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FINAL Corrective Measures Study

BASF Corporation
Former Ciba-Geigy Facility
180 Mill Street
Cranston, Rhode Island

June 20, 2014

Rev. September 21, 2015

Draft Final February 22, 2016

Final April 29, 2016

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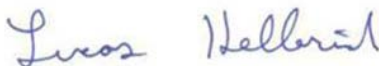
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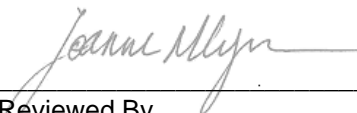
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List of Acronyms and Abbreviations

2X	Two Times
AOC	Area of Concern
BGS	Below Ground Surface
CAO	Corrective Action Objective
COCs	Constituents of Concern
CMS	Corrective Measures Study
CVOCs	Chlorinated Volatile Organic Compounds
CY	Cubic Yard
DEC	Direct Exposure Criteria
DO	Dissolved Oxygen
ERD	Enhanced Reductive Dechlorination
ELUR	Environmental Land Use Restriction
FPA	Former Production Area
FWWTA	Former Waste Water Treatment Area
HI	Hazard Index
I/C DEC	Industrial/Commercial Direct Exposure Criteria
IRM	Interim Remedial Measure
ISCO	In Situ Chemical Oxidation
ISCR	In Situ Chemical Reduction
µg/kg	micrograms per kilogram
MFR	Modified Fenton's Reagent
MCL	Maximum Contaminant Level
MIP	Membrane Interface Probe
MNA	Monitored Natural Attenuation
MPS	Media Protection Standards
NOAA	National Oceanic and Atmospheric Administration
OWLA	Office/Warehouse/Laboratory Area
O&M	Operations and Maintenance
P&T	Groundwater Pump and Treat
PPM	Parts Per Million
PCBs	Polychlorinated Biphenyl
PDI	Pre-design Investigation
PHERE	Public Health
PPM	Parts Per Million
QAPP	Quality Assurance Project Plan
RCRA	Resource Conservation and Recovery Act
RGs	Remedial Goals
RIDEM	Rhode Island Department of Environmental Management
R DEC	Residential Direct Exposure Criteria
RFI	RCRA Facility Investigation

List of Acronyms and Abbreviations (cont'd)

SMP	Soil Management Plan
SPLP	Synthetic Precipitation Leaching Procedure
SRI	Supplemental Remedial Investigation
SVE	Soil Vapor Extraction
SVOC	Semi-volatile Organic Compound
SWMU	Solid Waste Management Unit
TCLP	Toxicity Characteristic Leaching Procedure
TPH	Total Petroleum Hydrocarbons
TSCA	Toxic Substances Control Act
UCL	Upper Confidence Limit
USEPA	United States Environmental Protection Agency
VOC	Volatile Organic Compound
WWTA	Waste Water Treatment Area

Executive Summary

AECOM has prepared a Resource Conservation and Recovery Act (RCRA) Corrective Measures Study (CMS) on behalf of BASF for the former Ciba-Geigy facility located at 180 Mill Street in Cranston, Rhode Island (the Site). The objective of this CMS is to identify, develop and evaluate potential corrective measures to address impacted environmental media at the Site. This CMS was completed in accordance with the CMS Work Plan prepared by AECOM, and approved by United States Environmental Protection Agency (USEPA) on March 10, 2014.

The Former Ciba-Geigy facility was a chemical manufacturing facility operated by Alrose Chemical Company beginning in 1930. The facility was used for batch manufacturing of organic chemicals, such as plastic additives, optical brighteners, pharmaceuticals, and textile auxiliaries. Ciba-Geigy (referred to as Ciba herein) ceased all chemical manufacturing operations in May 1986 when the plant was closed. Following closure in 1986, the production facilities were demolished to grade, where building foundations and subsurface structures were left in place. The former office, laboratory and warehouse buildings were left in place (Buildings 26, 20, 25, and 15) and remain intact as of this writing.

Investigation and remediation activities at the Site have been conducted by Ciba (now BASF) under continuous regulatory oversight of the USEPA since 1989 as part of the RCRA Corrective Action program documented in the following regulatory orders:

- USEPA Consent Order RCRA No. I-88-1088 (1989); and
- USEPA Consent Order Modification to RCRA No. I-88-1088 (1992).

In 2009 BASF Corporation (BASF) acquired Ciba, and with it, BASF retains all regulatory responsibility for the Site.

Remedial investigations (RI) and interim remedial measures (IRM) were conducted at the facility from 1990 to 2009 by Ciba. Since 2010 BASF has reviewed all the Site-related files, and conducted its own remedial investigations to fill outstanding data gaps necessary to characterize remedial measures to advance this Site to final compliance under this RCRA corrective action. A summary of the history of RI and IRM activities is provided below as the context for the proposed additional remedial measures deemed necessary to achieve RCRA closure.

A multi-phase RCRA Facility Investigation (RFI) was completed between 1991 and 1995. A separate RFI was also completed for the Pawtuxet River in 1996. The RFIs concluded that unacceptable human health and ecological risks were present primarily from polychlorinated biphenyl (PCB) and volatile organic compound (VOC) impacts in Former Production Area soil and adjacent river sediment. Media protection standards (MPS) were then derived for PCBs in soil and VOCs (chlorobenzene, 1,2-dichlorobenzene, 2-chlorotoluene, xylenes, and toluene) in groundwater. IRMs were developed and implemented in 1995 and 1996 for soil (PCB excavation and capping and soil stabilization via the installation and operation of a soil vapor extraction system [SVE]), groundwater (installation and operation of a groundwater pumping and treatment system [P&T]), and sediment (excavation and capping). From 1996 to 2010 verification sampling of impacted media was conducted periodically to verify that the IRMs were functioning as intended. From 2010 to 2015, BASF conducted document review and RI tasks to validate IRM need and effectiveness. RI tasks included several rounds of soil, groundwater and sediment data collection and analysis. The results provided a refinement to the

previous environmental impact characterization and no significant exposure concerns or additional environmental impacts were discovered, thus validating the previous work performed by Ciba and the EPA.

From the BASF assessment, corrective measures for the remediation of remaining soil and groundwater impacts were screened for feasibility in the CMS Work Plan (AECOM 2014), and they are evaluated in this CMS to present alternatives that will achieve RCRA closure.

For the purposes of this CMS presentation, based on the extensive historical record of Site use, environmental data and remedial measures, the Site is separated into four sub-areas:

1. The Former Production Area (FPA) where all of the manufacturing operations occurred, where several areas of concern were identified, and where several IRMs were implemented.
2. Pawtuxet River sediments which were impacted by FPA waste discharges during facility operation and where an IRM was implemented.
3. The Office/Warehouse/Laboratory Area (OWLA), which was not identified as an area of concern by the EPA, but where Rhode Island Department of Environmental Management (RIDEM) rules and regulations apply.
4. The Former Waste Water Treatment Plant Area (FWWTA), which is located on a separate lot on Mayflower Drive, was identified as an area of concern by the EPA at the time of the RFI, and was the subject of a comprehensive property remedial investigation. Based on that investigation, no significant environmental impacts were identified. While Ciba sold the property in 2004, the property remains part of the RCRA Site because no EPA Statement of Basis was issued, and at a minimum, remedial measures must consider RIDEM rules and regulations.

In the CMS Work Plan (AECOM, 2014) potential remedial alternatives were screened based on feasibility criteria, and based on this analysis a set of technologies were retained for further evaluation in this CMS. Several additional tasks were conducted since approval of the CMS Work Plan, and they are:

1. Implementation of a bench-scale experiment to study the efficacy and design of an in-situ biological degradation technology to address impacted groundwater.
2. Implementation of a pre-design investigation to refine groundwater remediation areas.
3. Screening of additional groundwater remedial alternatives.

Corrective Action Objectives (CAOs) provide the basis for remediation and summarize the remedial goals for corrective measures. On a RCRA Site-wide basis, the objective is protection of human health from unacceptable exposure to environmental impacts at the Site (unacceptable is defined as cancer risk greater than 1×10^{-4} and Hazard Index > 1), and protection of the environment from exposure to impacts at the Site.

At the FPA, soil and groundwater media require remedial action to provide for long-term protection of human health and the environment. With respect to soil, the presence of PCBs is the regulatory driver for remediation. The list of retained soil remediation alternatives is provided below:

- No action
- Engineered and/or institutional controls (land use restrictions)

- Low Occupancy Re-Use Scenario (Excavation/Capping with land use restrictions)
- High Occupancy Re-Use Scenario (Excavation/Capping with land use restrictions)
- Strictest Remedial Standard (Excavation)

For groundwater, VOCs are the regulatory drivers for remediation due to their concentrations. The list of retained groundwater remediation alternatives is provided below:

- No action
- Engineered and/or institutional controls
- Monitored natural attenuation (MNA)
- In situ chemical oxidation (ISCO)
- In situ aerobic biodegradation
- Groundwater P&T – repair and operate existing system

The CAO for Pawtuxet River sediment is to ensure the existing cap integrity is protective of the environment. To meet the CAO for Pawtuxet River sediment, given the historic remedial measures completed for sediment at the Site (i.e., excavation and capping), a long-term, periodic monitoring and reporting program is proposed to ensure the existing sand cap remains intact.

For the OWLA, while it did not constitute an AOC during the RFI, soil and groundwater sampling conducted by BASF in 2012 through 2014 indicate sporadic soil impacts of several polycyclic aromatic hydrocarbons (PAH) typical of urban environments (e.g., residues from vehicle exhaust and runoff from paved surfaces) in excess of the RIDEM Industrial/Commercial Direct Exposure Criteria (I/C DEC). These impacts will need to be addressed as per RIDEM Regulations, and to this end BASF will remove or cover the affected soil, impose an Environmental Land Use Restriction (ELUR) for this area, and include a soil management plan to be applied as part of any redevelopment work.

For the FWWTA, the alternatives for RCRA closure include No Further Action and imposing a RIDEM Environmental Land Use Restriction (ELUR) on the property.

The retained remediation alternatives were screened against a series of performance standards as specified in USEPA CMS guidance. The performance standards used in the detailed analysis of remedial alternatives are as follows:

- Primary performance standards, including:
 - Overall protection of human health and the environment
 - Attainment of media cleanup standards
 - Control of the sources of releases
- Balancing factors (used to further evaluate alternatives meeting all three primary performance standards)
 - Long-term reliability and effectiveness
 - Reduction in the toxicity, mobility, or volume of wastes
 - Short-term effectiveness
 - Implementability and environmental footprint

- Cost
- State and community acceptance

Based on detailed analysis of the retained alternatives the following remedy is proposed to address COCs in soil at the Site:

FPA:

Remediate PCB-impacted soil to meet a High Occupancy Re-Use scenario. The goal associated with this remedy is to allow the entire FPA to be repurposed as publically-available open space (parkland). This will be achieved by removing soil containing PCBs greater than 10 ppm and installing a clean soil cover (cap) over areas where soils contain PCBs greater than 1 ppm. The soil cover will be constructed and maintained to support an ecologically varied upland habitat.

The remedy will follow a four step plan consistent with both EPA (TSCA) and RIDEM requirements: [1] Excavation, verification sampling and offsite disposal of all TSCA-classified soil (i.e., soil impacted with greater than 50 ppm of PCBs); [2] Excavation, verification sampling and offsite disposal of all soil impacted with greater than 10 ppm of PCBs (i.e., the EPA requirement to allow for a high-occupancy reuse scenario); [3] Cover (cap) remaining soils with concentrations greater than 1 ppm with two feet of clean soil and confirmatory sampling to meet RIDEM direct exposure requirements. The cap will be completed to support a diverse upland habitat; [4] Impose an Environmental Land Use Restriction (ELUR) on the parcel, to be approved by the RIDEM, requiring, at a minimum, open space (parkland) reuse only and long-term cap maintenance and monitoring. Details of the four step plan will be provided during the design-phase of the corrective action.

Remediate VOC-impacted Groundwater to restore the upland aquifer and protect the Pawtuxet River. Groundwater will be addressed through a three step plan. First, residual VOC source material located in the upland near SWMU11 will be in part excavated from the vadose zone and disposed of offsite and in part destroyed in-situ with a chemical oxidant (activated sodium persulfate) by physically mixing the oxidant into the vadose and saturated zones before re-grading the area to support the soil cover.

Second, for the groundwater plume that has migrated to the vicinity of the river bulkhead, an in-situ reactive barrier will be installed parallel to the river bulkhead and normal to the groundwater flow direction to destroy VOC mass in-situ before it migrates off-site and discharges to the Pawtuxet River. The proposed oxidant is ozone, and it will be applied to the aquifer in a continuous fashion using a line of wells that overlap in their volume of influence (a sparge application). The ozone will destroy all contamination in which it comes in contact, and it will also contribute oxygen to the groundwater to support aerobic biological degradation. Remedy performance will be monitored using dedicated wells installed upgradient, within and downgradient of the barrier along flow lines. The remedy will be run on the order of years until such time as downgradient monitoring shows that the media protection standards are consistently met. The remedy design including the treatment volume, number and orientation of injection wells, and monitoring requirements will be determined from a pilot testing program.

Third, for dissolved upland VOC mass in general, monitored natural attenuation (MNA) will be used to show aquifer restoration over time. A monitoring program will be implemented to analyze trends of COCs and pertinent MNA parameters upgradient and downgradient of the reactive barrier. The performance monitoring parameters and frequency will be outlined in a Remedial Action Work Plan, but they typically include sampling for the COCs, geochemistry (e.g. dissolved oxygen, specific conductivity, pH, turbidity), total organic carbon, terminal electron acceptors (e.g. nitrate, sulfate, iron), and

occasional bacterial census to evaluate whether bacterial populations at the Site continue to be present in sufficient numbers to effectively treat COCs. Performance monitoring evaluations will be conducted in concert with the ISCO barrier performance evaluations to determine whether natural attenuation is sufficient to address groundwater impacts in concert with or independently of the ISCO barrier approach. It is anticipated that over time MNA will become the sole groundwater remedy based on the record of spatial and temporal trends in COC concentration.

These remedial measures in concert are appropriate given site-specific conditions including extensive in place building foundations which limits access to aquifer materials and low conductivity heterogeneous aquifer material coupled with the age of the impacts (greater than 40 years) which limits the mobility of the dissolved-phase mass. Finally, this remedy is consistent with that proposed for the upland soils and the imposition of an ELUR that will limit future land use to open-space and require long-term operation and maintenance.

Pawtuxet River Sediment

Given the historic remedial measures completed for sediment at the Site, a long-term periodic monitoring program will be implemented to ensure the existing sand cap remains intact and protective. Monitoring frequency is initially proposed to occur at the first five year review (2021) and after major flood events between now and that time (defined by NOAA as a Pawtuxet River stage that exceeds 13 ft MSL at the USGS gage station 01116500). Under the monitoring plan the sand cap will be sampled for PCB content to ensure that any remaining PCBs sequestered below the cap are not permeating the cap. Cores of the cap will be collected along the center line at upstream, midstream and downstream locations (3 cores) and samples will be collected for PCB analysis from the 0" to 3" and 3" to 6" horizons (2 samples per core). If PCBs exceed 1 ppm in any sample, additional investigation will be conducted to determine the source of the detections and appropriate remedial measures necessary to ensure protectiveness, if any. A detailed monitoring and sampling plan will be developed following this outline. At the time of the 5 year review, based on the data in hand, a decision will be made as to the permanence of the remedy and future monitoring requirements.

OWLA

To address RIDEM Regulations, BASF will remove or cover the soil with exceedances of the I/C DEC and impose an ELUR for this area to be approved by the RIDEM. The ELUR will include the following restrictions: non-residential use only, must employ a soil management plan for any invasive work conducted on the property, and must, on an annual basis, report to the RIDEM that the terms of the ELUR are being met.

FWWTA

The property was sold in 2004. To date, the USEPA has not issued a Statement of Basis outlining the regulatory decision on the property, and as such, it remains part of this CMS. Soil characterization data include sporadic detections of a commonly used insecticide, chlordane, naturally occurring arsenic, and benzo(a)pyrene and dibenz(a,h)anthracene, which are commonly identified in urban settings. These data are located within the 200-foot riverbank wetlands zone, which precludes development and soil management without RIDEM approval. Further, a human health risk assessment completed in 1995 (Ciba, 1995) determined that there was no significant risk for a conservative future use scenario of an on-site resident (despite the commercial zoning designation). Therefore, the remedy for this area is No Further Action.

1.0 Introduction

This Resource Conservation and Recovery Act (RCRA) Corrective Measures Study (CMS) has been prepared on behalf of BASF Corporation (BASF) for the former Ciba-Geigy facility located at 180 Mill Street in Cranston, Rhode Island (the Site) and a former Waste Water Treatment Area (FWWTA) located at Mayflower Drive in Cranston, Rhode Island. The objective of the CMS is to identify, develop and evaluate corrective measures (remedial actions) to address impacted environmental media at the Site. In 2009 BASF Corporation (BASF) acquired Ciba Specialty Chemicals [Ciba] (the successor to Ciba-Geigy), and, as Site owner, BASF is currently involved in an ongoing, comprehensive RCRA Corrective Action Program at the Site. This program is being governed by RCRA Consent Order No. I-88-1088 (1989) and Consent Order Modification to RCRA No. I-88-1088 (1992) between the United States Environmental Protection Agency (USEPA) Region I and BASF. This CMS is being prepared to satisfy the requirements of the consent orders and has been developed in accordance with the CMS Work Plan (AECOM, 2014), approved by USEPA on March 10, 2014.

1.1 Corrective Measures Approach and Site-Specific Purpose

For the purposes of this CMS presentation, based on the extensive historical record of Site use, environmental data and remedial measures, the Site is separated into four sub-areas:

1. The Former Production Area (FPA) where all of the manufacturing operations occurred, where several areas of concern were identified, and where several IRMs were implemented.
2. Pawtuxet River sediments which were impacted by FPA waste discharges during facility operation and where an IRM was implemented.
3. The Office/Warehouse/Laboratory Area (OWLA), which was not identified as an area of concern by the EPA, but where Rhode Island Department of Environmental Management (RIDEM) rules and regulations apply.
4. The Former Waste Water Treatment Plant Area (FWWTA), which is located on a separate lot on Mayflower Drive, was identified as an area of concern by the EPA, and was the subject of a comprehensive property remedial investigation. At the time of the remedial investigation, no significant environmental impacts were identified. While Ciba sold the property on 2004, the property remains part of the RCRA Site because no EPA Statement of Basis was issued, and at a minimum, remedial measures must consider RIDEM rules and regulations.

The purpose of the CMS portion of the RCRA corrective action process is to identify, evaluate and propose remedial technologies and alternatives for addressing potentially hazardous constituents associated with these areas. Remedial technologies not presented in this CMS were excluded during the development of the CMS Work Plan (AECOM 2014) based on site conditions and contaminant and technology characteristics.

The CMS is designed to address the following objectives:

- Identify media-specific cleanup standards;

- Identify potential treatment technologies, containment/disposal, and institutional/engineering control options for soil, sediment, and groundwater that contain COC impacts above established cleanup standards;
- Screen feasible remedial technologies;
- Assemble technologies into alternatives;
- Analyze the identified alternatives using specific evaluation criteria and media cleanup standards;
- Compare alternatives against each other using the evaluation criteria; and
- Recommend remedial alternatives.

1.2 Report Organization

This CMS is organized into nine sections.

- **Section 1.0** presents the introduction, a summary of the CMS objectives and the purpose of the CMS.
- **Section 2.0** presents a brief history and current status of the Site.
- **Section 3.0** summarizes the corrective measure objectives as they pertain to the applicable federal and state remediation standards.
- **Section 4.0** presents a summary of screening process for the remedial alternatives selected in the CMS Work Plan. This section is further organized to present remedial alternatives by media
- **Section 5.0** presents a detailed analysis of selected corrective measure alternatives.
- **Section 6.0** presents an evaluation of the selected corrective measure alternatives.
- **Section 7.0** presents the references used herein.

2.0 Site History and Current Status

2.1 Site History

The Site was a chemical manufacturing facility operated by Alrose Chemical Company beginning in 1930. It consists of the FPA, the Pawtuxet River sediments, the OWLA and the FWWTA (**Figure 1**).

The Geigy Chemical Company of New York purchased the facility in 1954 and later merged with the Ciba Corporation in 1970. The facility was used for batch manufacturing of organic chemicals, such as plastic additives, optical brighteners, pharmaceuticals, and textile auxiliaries (Ciba, 1995). Ciba-Geigy (Ciba) ceased all chemical manufacturing operations in May 1986 when the plant was closed. Following closure in 1986, the production facility was demolished to grade, where building foundations and subsurface structures were left in place. The former laboratory and warehouse buildings were left in place (Buildings 26, 20, 25, and 15) in the northern portion of the Site. **Figure 2** shows the current layout of the Production Area and where historic site structures/features were located. The FWWTA that is located on Mayflower Drive, and it was decommissioned and sold in 2004. A detailed history of the Site, Site use, and an overview of applicable regulatory drivers and requirements were provided in the Phase II RCRA Facility Investigation (RFI) (Ciba-Geigy Corporation, 1995).

In 2009, BASF Corporation (BASF) acquired Ciba, and with it, BASF retains all regulatory responsibility for the Site. BASF conducted additional characterization of groundwater and soil and derived an updated conceptual site model for the Site. This work is documented in the Supplemental Remedial Investigation (SRI) Report (AECOM, 2012) and SRI Revision (AECOM Draft, 2014; Final 2016).

2.2 Regulatory History and Status

As with many other industrial facilities with long operational histories, contaminants of concern (COCs) have been identified at the Site. Some of these COCs eventually migrated to groundwater at the FPA and were found in the aquifer and sediment beneath the Pawtuxet River adjacent to the FPA.

Investigation and remediation activities at the Site have been conducted by Ciba (now BASF) under continuous regulatory oversight of the USEPA since 1989 as part of the RCRA Corrective Action program documented in the following regulatory orders:

- USEPA Consent Order RCRA No. I-88-1088 (1989); and
- USEPA Consent Order Modification to RCRA No. I-88-1088 (1992).

Remedial investigations (RI) and interim remedial measures (IRM) were conducted at the facility from 1990 to 2009 by Ciba. Since 2009, BASF has reviewed all the Site-related files, and conducted its own remedial investigations to fill outstanding data gaps necessary to characterize remedial measures to advance this Site toward final compliance under this RCRA corrective action. A summary of the history of RI and IRM activities is included below to provide context for proposed additional remedial measures deemed necessary to achieve RCRA closure.

- FPA and OWLA investigations are described in the Supplemental Remedial Investigation (SRI) Report (AECOM, 2012) and SRI Revision (AECOM Draft, 2014; Final 2016).
- The Phase II RFI (Ciba, July 31, 1995) included Site source characterization, soil and groundwater characterization, and fate and transport and risk evaluation.
- The Pawtuxet River RFI (Ciba, March 31, 1996) included physical characterization, source characterization, release characterization and river modeling investigations as well as a Baseline Ecological Risk Assessment.
- Remediation activities for the FPA soil, groundwater and sediment are described in the On-Site Corrective Measures Study (Woodward-Clyde, 1995), On-Site Soil Interim Remedial Measures (Woodward-Clyde, 1996), Sediment IRM for the Pawtuxet River (Woodward-Clyde, 1996), and the Sediment IRM Report (AECOM, 2012).

The Phase II RFI was completed and documented in a report to USEPA (Ciba, 1995). A Public Health and Environmental Risk Evaluation (PHERE) was completed as part of the RFI, per the Order (USEPA, 1989). The PHERE evaluated potential human health and ecological risks associated with each operational area. For the FPA unacceptable human health and ecological risks were identified primarily from PCB and VOC impacts in soil, groundwater, and sediment. To mitigate these impacts and provide a basis for necessary Interim Remedial Measures (IRM), site-specific Media Protection Standards (MPS) were developed. The IRMs were developed and implemented in 1995 and 1996 for soil (PCB excavation and capping and soil stabilization via the installation and operation of a soil vapor extraction system [SVE]), groundwater (installation and operation of a groundwater pumping and treatment system [P&T]) and sediment (excavation and capping). The SVE system was operated from 1997 to 2005, when, based on the conditions that it had reached its asymptotic end point and post-operation verification sampling showed that the MPS was achieved, it was determined that the system had addressed the soil impacts. The P&T operated from 1996 to 2006 when performance monitoring showed that the MPS had been achieved. Continued monitoring showed a rebound in concentrations in the southeast corner of the property in 2008, and this triggered a remedial investigation to delineate the recalcitrant zone, and remediation of this zone is in part the subject of this CMS.

Since the Phase II RFI (RFI On-Site Areas, Ciba Corporation, 1995), a significant amount of field work has been completed in the FPA and OWLA, including IRM implementation and verification monitoring conducted by Ciba through 2009 and remedial investigation activities conducted by BASF from 2010 through 2015. Based on the findings of the SRI (AECOM, 2012), SRI Revision (AECOM Draft, 2014; Final 2016), and additional pre-design investigation (PDI) data collected to refine groundwater remediation areas (completed during September 2014), well-delineated areas of soil and site-related groundwater at the FPA were found to require remedial action over and above the IRM measures previously applied. Specifically, this characterization shows that subsurface soils contain PCBs above current remediation standards, and there is a localized groundwater zone that is impacted with site COCs above the MPS.

While the OWLA was not identified as an AOC during the RFI, soil and groundwater sampling conducted by BASF in 2012 through 2014 indicate sporadic soil impacts of several polycyclic aromatic hydrocarbons (PAH) typical of urban environments (e.g., residues from vehicle exhaust and runoff from paved surfaces) in excess of the RIDEM Industrial/Commercial Direct Exposure Criteria (I/C DEC). These RIDEM criteria are applicable or relevant and appropriate requirements (ARARs) that will need to be addressed.

With regard to the Pawtuxet River sediments, a Phase II RFI was completed by Ciba-Geigy in 1996 (RFI Pawtuxet River, Ciba Corporation, 1996). The RFI concluded that excavation, disposal and capping of impacted sediment from the former cofferdam area in the river adjacent to the FPA would significantly reduce the concentrations of Site COCs in river sediment. This assessment provided the basis for a subsequent IRM to provide “significant, long-term reductions in contaminant concentrations” within the Upper Facility Reach of the Pawtuxet River, where over 2,225 tons of contaminated sediment was excavated and replaced with clean sand (Sediment IRM Pawtuxet River, 1996). Periodic sediment sampling conducted by Ciba verified the intent of the IRM. Moreover, after a 100 year flood event in 2010 and following a request by the EPA, BASF confirmed that the sand cap emplaced over the former cofferdam area and witness barrier were still present (AECOM, 2012). Additional sediment sampling immediately upstream and downstream of the capped area was also completed at that time. While the cap was shown to be intact and functioning as intended, sediment analytical results outside the capped area indicated that three discrete areas of sediment continued to contain residual PCBs. In 2012, BASF voluntarily addressed these areas by excavation and capping with clean sand. A total of 23 CY of impacted sediments were removed from the Pawtuxet River and disposed off-site at appropriate facilities (AECOM, 2012).

Figure 3 illustrates the IRMs completed in the FPA related to soil, groundwater, and sediment in the Pawtuxet River adjacent to the FPA.

With regard to the FWWTA, the RFI risk evaluation concluded that risk associated with site-related soil and groundwater impacts met the conditions for unrestricted future use. Groundwater did not exceed any applicable risk-based standard. For soil, this conclusion was based on the risk calculation result that the hazard index (HI) for non-cancer compounds was less than 1 (actual HI = 0.4), and the total lifetime cancer risk was 3×10^{-5} , which is within the USEPA target risk range of 1×10^{-4} and 1×10^{-6} . Given the conclusions of the risk evaluation, no IRMs were required for the FWWTA.

It is important to note that the more recent characterization conducted by BASF is consistent with that derived during the original RFI in terms of COCs, their location and magnitude, and protective exposure assumptions. In addition, it provides a data-based refinement of the nature and extent of site-related impacts upon which to design and implement additional corrective actions to achieve RCRA closure.

For the sub-sections that follow the reader is referred to the following figures that illustrate the major site attributes including: hydrogeology (**Figure 4A** and **4B** are groundwater flow maps and **Figure 5** is a hydrogeologic cross section), investigation sampling locations (**Figure 6** provides multi-parameter groundwater and soil sampling locations and **Figure 7** provides PCB sampling locations), groundwater impacts above relevant regulatory standards (**Figure 8**), and PCB distribution in shallow soils (**Figure 9**).

2.3 Site Geology and Hydrogeology

Detailed summaries of the geology and hydrogeology of the Production Area are included in the 1995 RFI submitted to USEPA by Ciba Corporation (1995). The stratigraphy of the production area is characterized based on data from the Stabilization Investigation Report and Design Concepts Proposal (Ciba, 1993), the RFI (Ciba, 1995) and the recent soil borings completed on-site between 2007 and the present. The comprehensive representation of the hydrogeology is provided in **Figures 4A and 4B**.

The production area is underlain by urban fill (2 to 8 feet thick), including sand, silt and gravel, as well as concrete and metal debris. Below the fill is a silty sand unit (10 to 15 feet thick) of alluvial origin. In the southwest quadrant of the area a fairly homogeneous unit of gray silt of alluvial origin is present (2 to 10 ft in thickness beginning approximately 10 to 15 ft below the ground surface and of low hydraulic conductivity). Below these units (where present) exists a heterogeneous mixture of gray sand, silt, clay, and gravel of glacial outwash origin). A unit of relatively homogeneous fine sand and silty sand is the next unit encountered in depth. Finally, a 5 to 10 foot thick glacial till unit directly overlies bedrock in the Production Area. The top of competent bedrock is present from 50 to 59 ft bgs. A description of bedrock as a quartz-biotite sandstone in the Production Area was included in the Phase IA Report (Ciba, 1991) and Phase II RFI (Ciba, 1995). A cross sectional representation of Site stratigraphy is included as **Figure 5**.

With regard to hydrogeology, shallow and deeper groundwater flow direction is generally to the southeast toward the Pawtuxet River. The water table is approximately 7 to 10 feet below the ground (ft bgs) surface across the Production Area. The vertical gradient is generally downward across the Site indicating that groundwater recharge conditions prevail. The natural discharge point for site-related groundwater is the Pawtuxet River, which is a gaining water body adjacent to the Site, as evidenced by the fact that the river stage is lower than the groundwater elevation. The groundwater flow is affected by a bulkhead wall (sheet piling) that extends to a depth of 25 ft bgs, where groundwater is deflected downward under the wall as it migrates toward the river.

2.4 Remedial Action History Summary

Multiple IRMs associated with the FPA have been implemented to address Site COCs. These include several phases of soil IRMs to address PCBs, a SVE system to address VOCs in soil, a sediment excavation and capping IRM to address PCBs and VOCs, and groundwater pump-and-treat and soil vapor extraction to reduce VOC mass in groundwater and soil. **Figure 3** provides a location map for these IRMs.

2.4.1 FPA Soil IRM

The soil data collected during the Supplemental RI (2011 to 2014) and the confirmatory soil data collected during the Revised On-Site IRM (Woodward-Clyde, 1995) were combined and presented in tabular and graphical format in the SRI Report (AECOM, 2014). See **Figures 8 and 9** which are based on the data presented in Tables 4-3 and 4-4 of the SRI (AECOM Draft 2014; Final 2016). The Revised On-Site IRM describes four phases of excavation and capping with clean soil in the FPA to remediate PCB concentrations in soil that exceeded the Site MPS for PCBs with a safety factor applied (i.e., soil containing total PCBs greater than 45 ppm) [excavation extent provided in **Figures 3 and 9**]. Inherent in the IRM was the fact that impacted soil remaining below the soil cap would eventually be capped with a more robust material to eliminate potential receptor contact.

2.4.2 Pawtuxet River Sediment IRM

The Phase II RFI (Ciba-Geigy, 1996) concluded that excavation, disposal, and capping of impacted sediment from the former cofferdam area in the river adjacent to the FPA would significantly reduce the concentrations of Site COCs in river sediment (see location in **Figure 3**). This assessment provided the basis for implementing an IRM to provide “significant, long-term reductions in contaminant concentrations” within the Upper Facility Reach of the Pawtuxet River, where over 2,225 tons of contaminated sediment were excavated and replaced with a clean sand cap (Sediment IRM Pawtuxet River, 1996). After a flood event in 2010, in 2010/2011 BASF sampled the capped area and found it to be functioning as intended. Additional sediment samples collected at the time upstream and

downstream of the capped area adjacent to the Site detected three local areas of previously unidentified elevated site-related impact. These areas were subsequently excavated, where a total of 23 cubic yards (CY) of sediment were removed and disposed off-site at appropriate facilities (AECOM, 2012).

2.4.3 Groundwater Pump and Treat/Soil Vapor Extraction System

In 1995 and 1996, the groundwater IRM was initiated in the FPA with installation and operation of a soil vapor extraction system [SVE]) and installation and operation of a groundwater pumping and treatment system [P&T] (locations shown in **Figure 3**). The SVE system was operated from 1997 to 2005, when, based on the conditions that it had reached its asymptotic end point and post-operation verification sampling showed that the MPS was achieved, it was determined that the system had addressed the soil impacts.

The P&T system operated from 1996 to 2006 when performance monitoring showed that the MPS for groundwater had been achieved. Continued monitoring showed a rebound in concentrations in the southeast corner of the property in 2008. The P&T system was re-activated and operated until the flood of April 2010 damaged several components of the system. From 2011 to 2014, BASF completed several remedial investigations at USEPA's direction to refine the conceptual site model and address any on-going Site-related groundwater impacts (documented in AECOM 2014 and see current groundwater impact **Figure 8**).

2.5 Characterization of the FPA, OWLA, and Pawtuxet River Sediments

The site-specific geology and hydro stratigraphy was derived from both historical records and past and recent boring logs (documented in AECOM, 2014 and see **Figure 5**). In general, the FPA is underlain by predominately fine grain, low permeability, sands and silts with locally coarser deposits from glaciofluvial origin (~ 50 ft thick). In the southwest quadrant of the FPA there is an extensive heterogeneous aquitard that separates a shallow and a deep aquifer. In general the permeability of the deposits decrease as one moves east to west across the site as evidenced by the production rates of wells PW-110 (40 gpm) and PW-130 (20 gpm) and PW-120 (2 gpm). The shallow geology is affected by subsurface structures (e.g., foundations and pilings) left in place during plant demolition.

In 2011 BASF conducted a thorough review of the available site reports and data in order to fully understand the nature and extent of contamination at the property and identify data gaps to support the nature and extent assessment (also called conceptual site model [CSM] development). The CSM in turn is used to derive a necessary and sufficient remedial strategy for the property. The gap analysis and CSM are presented in AECOM (2012) and further refined here with additional data collected in September 2014.

Based on historical operations and environmental data, AECOM (2012) identified areas across the property that required additional investigation. During the 1990/1991 RI (Ciba, 1991), several Solid Waste Management Units (SWMU) and Areas of Concern (AOC) were identified in the FPA, and these areas were assessed retaining the original nomenclature. In addition to the previously identified areas referenced above, AECOM (2012) identified several additional areas based on the historical record. All these areas were reviewed for completeness of characterization, data gaps were identified, and a sampling plan was derived and implemented to fill data gaps regarding ongoing environmental impact (AECOM, 2012). A description of each area is presented below including current residual impact and characterization completeness. These historical operational areas are presented on **Figure 2** and described in **Table 1**. The soil and groundwater sampling locations collected from 2011 to 2014 are shown on **Figures 6 and 7**.

Associated with the FPASWU 2, 3, 7: SWMUs 2, 3, and 7 contain a former tank farm area where rail cars were off-loaded and loaded. Secondary containment was present and no spills were noted in the record. The area was initially assessed by sampling during the 1995 RFI (Ciba, 1995). Additional soil data were collected in 2012. No VOC detects were noted; SVOC detections were low and near the detection limit. Neither metals nor pesticide concentrations exceeded the RIDEM DEC industrial/commercial levels. Total PCBs were identified, but this impact is consistent with site-wide PCB impacts observed throughout the Production Area. These former SWMUs do not represent an ongoing data gap, and no further action is warranted.

SWMU 4: SWMU 4 was an area that contained a trash compactor where solid wastes were disposed. VOCs, SVOCs, metals, and pesticides did not exceed RIDEM DEC industrial/commercial standards. This was confirmed with soil sampled in 2012. A detection of total PCBs was noted to be >10 ppm from 4-6 ft bgs, but this is consistent with site-wide PCB impacts observed throughout the Production Area. This former SWMU does not represent an ongoing data gap, and no further action is warranted.

SWMU 8: A historic spill was noted at nearby SWMU 4 and a former Site plan shows a solvent recovery facility in this area, which had not been previously identified as a specific AOC or SWMU. Sampling was performed in 2012 to evaluate this area. No impacts to surface soil by VOCs, SVOC, metals, or pesticides were noted to exceed RIDEM DEC industrial/commercial standards. A detection of total PCBs greater than 10 ppm from 0-2 ft bgs was documented, but this is consistent with site-wide PCB impacts observed throughout the Production Area. Adjacent groundwater monitoring locations, GW-10 and MW-13S, did not contain any detectable VOC concentrations. This former SWMU does not represent an ongoing data gap, and no further action is warranted.

SWMU 11: A documented toluene spill from a pipeline to a subsurface sump at Building #11 occurred in the early 1980s. An IRM SVE system was operated from 1997 to 2005 (see **Figure 3** for location) to address this release, and post-closure monitoring indicated that COCs were remediated (Ciba 2005). Soil/aquifer probing was conducted from 2012 to 2014 to delineate PCB impact in shallow soil and VOC impact in both shallow and deep soil to 40 ft bgs. Detections of total PCBs were generally observed in shallow soil consistent with site-wide PCB impacts observed within the Production Area in general and impacts observed at Buildings 10 and 18 in particular (**Figure 9**). These residual impacts will be addressed as part of the proposed soil remedial measures. The VOC data showed toluene and 2-chlorotoluene at elevated concentrations in shallow soil, at 2-6 feet bgs, in the southwest corner of this area. This area is within the SVE treatment area (**Figure 3**). PDI soil and groundwater data were collected during September 2014 from areas downgradient of the shallow soil VOC impacts. Elevated concentrations of COCs, primarily toluene and 2-chlorotoluene, were identified in shallow and deep groundwater and soil collected below the water table. Groundwater impacts are illustrated in **Figures 10A-J and Figures 11A-E**. These residual impacts will be addressed as part of the proposed soil and groundwater remedial measures.

Non-Aqueous Phase Liquid (NAPL) Area Near MW-34D: During installation of MW-34D in 1993, a separate phase liquid was observed, and it was assumed to be Dowtherm (a PCB-free cooling oil used in the former manufacturing process), but no confirmation sampling was completed on this material at the time. In 2012 characterization data were collected for groundwater and no indication of NAPL or dissolved residual was observed. The only indication of impact was observed at well MW-34S, where total xylenes were detected over its MPS (0.145 mg/L versus 0.078 mg/L). Shallow soil samples in the vicinity of MW-34 showed no impacts of VOCs. This well is located between the impacts observed at and downgradient of SWMU 11 to the north and the recalcitrant VOC impact zone associated with the Jet Sump Area (see next) to the south. Aquifer heterogeneity may account

for this discrepancy in continuity, and it will be investigated as part of the remedial measures that address groundwater.

Jet Sump Area: In Building 16 a boiler plant jet sump, where steam, charged with process-related solvent, was condensed before being recycled, failed in the mid-1970s. Excessive erosion associated with the failure went undetected and much of the condensate percolated into the subsurface. This area has been the subject of additional remedial investigation since 2008 based on both the documented history of use and the spatial and temporal trends in groundwater quality collected as part of the groundwater IRM (pumping and treatment system). This area, including the footprints of Buildings 16, 19, 22 and 23, coincides with the elevated soil and groundwater VOC data collected from 2008 to 2014 (see **Figure 8**). It represents a unique zone of recalcitrant VOC mass in soil and groundwater that has been adequately delineated and that will be addressed as part of the proposed soil and groundwater remedial measures.

Buildings #10/#18 Boiler Room & Transformers: Historically, this area contained boilers and transformers. The area was initially assessed by soil sampling during the 1995 RFI (Ciba, 1995). To evaluate current soil and groundwater conditions, additional data were collected. TPH samples collected from the area were below screening levels and no impacts from the boilers appear to have occurred. Total PCBs were detected at a concentration of 71.8 ppm at a depth of 4-6 ft bgs, adjacent to the transformer area. These residual impacts will be addressed as part of the proposed soil remedial measures.

Building #24 Zinc Rail Car Area: Dry chemicals were loaded into rail cars at this location. Soil samples collected in 2012 did not contain zinc above RIDEM DEC screening levels nor do these samples contain other COCs. This area does not represent an ongoing data gap, and no further action is warranted.

Building #21 Zinc Sump: Soil samples were collected in 2012 to delineate zinc surrounding the zinc sump. Soil samples did not contain zinc above RIDEM DEC screening levels. However, a soil sample collected from 0-2 ft bgs contained 36.7 ppm total PCBs and another sample contained 19.3 ppm total PCBs. These detections are likely due to mechanical transport during facility demolition, for example from the area in and around buildings 10 and 18. These residual impacts will be addressed as part of the proposed soil remedial measures.

Building #21 Tank Farm: Historically, this was a tank farm that supported pharmaceutical manufacturing activities in Building #21. The data support the characterization that this area is at the northern edge of the residual impacts referenced for the Jet Sump Area, but that it was not a source for impacts currently observed. Thus, the area has been adequately delineated.

Piping Runs: The underground piping transported manufactured material from building to building on-Site. The only documented release from the piping was the toluene release at Building 11 in the 1980s (subject to the SVE IRM). PDI data collected in September 2014 shows that the extent of the impact from SWMU 11 has migrated south of the area remediated by the SVE and in the area of the piping run. The data show that the contaminants are primarily toluene and 2-chlorotoluene, but the other COCs with MPS are present as well. In addition to the VOCs, soil adjacent to the run is impacted by PCBs, but this is consistent with site-wide PCB impacts observed. COCs were detected in soil at the southern end of the run, which terminates in the Jet Sump impact area, and where 2-chlorotoluene, toluene, and chlorobenzene are detected above their respective MPS. The PCB and VOC impacts will be subject to remedial action.

Hot Sump: The Hot Sump was connected to the outfall to the river cofferdam water treatment area, where sediment impacts were delineated and removed during the Pawtuxet River IRM. Groundwater and soil data show that residual contamination is not present in this area. This area does not represent an ongoing data gap, and no further action is warranted.

Septic Tank: Based on historical information, the site previously utilized one septic system for sanitary wastewater disposal prior to Ciba building a wastewater treatment plant off-Site in 1975. The associated sewage tank is located to the east of Building 14. No soil or groundwater impacts in the vicinity of this area were apparent from 2012 sampling. The septic tank was found to be present and intact, and it will be properly abandoned during remediation of PCB impacted soil in the FPA.

UST Vault/Underground Tunnel: Former USTs and a below-ground vault located on the eastern portion of the production site were decommissioned according to BASF staff interviews, but no confirmatory sampling or closure reporting exists. Facility staff were able to find photo-documentation of the UST removal. Soil and groundwater samples collected adjacent to the former vault had no detections of Site COCs. The tunnel access was reportedly sealed and the tunnel filled with crushed building material during plant decommissioning. This area does not represent an ongoing data gap. No further action for this SWMU is warranted.

Loading Dock: Manufactured chemicals were shipped off-site from area. No spills or releases were documented to have occurred. Soil samples collected in 2012 were analyzed for metals, pesticides, VOCs, SVOCs, and PCBs. There were no detections above the RIDEM DEC levels. This area does not represent an ongoing data gap, and no further action is warranted.

AOC 13 - The main manufacturing area was considered an Area of Concern based on past operations and investigated in the 1995 RFI (Ciba, 1995). This area comprised the entirety of the FPA. Recent data gap investigations have focused on discrete areas within this AOC, as described in the sections presented above (i.e., Building 16/Jet Sump Area, Building #10/#18, Building #21, Building #21 Tank Farm, Hot Sump, Piping Runs, Building #24 Zinc Sump, MW-34D area).

Associated with the OWLA: Based on historical operation data, except for AAOI 15, the area north of the railroad spur that housed the plant's offices, laboratory, warehouse, and parking was not considered an area of concern by the EPA. While this is the case, for completeness BASF identified this area for baseline sampling of soil, soil gas, groundwater and indoor air to verify this assessment.

AAOI 15 was identified during the RFI based on the presence of a laboratory sump and discharge piping that may have been used to dispose of waste. At that time, this area was discounted as a potential AOC because the sump area was sampled and no significant impacts were identified in the RFI. To verify this conclusion, investigation sampling in 2013 showed no elevated detections of VOCs, metals, pesticides or PCBs in this area. However, on the east side of building 15 near the sump location, two compounds, benzo(a)pyrene and dibenzo(a,h)anthracene were elevated above the RIDEM DEC levels for industrial/commercial use in shallow soil (0.5' bgs). These compounds are common in urban environments and the detections are likely attributable to vehicle exhaust particulate deposition and/or water runoff from paved surfaces. This area does not represent an ongoing data gap.

Additional soil sampling in the OWLA also showed no elevated detections of VOCs, metals, pesticides or PCBs in soil. However, as with AAOI 15, benzo(a)pyrene and dibenzo(a,h)anthracene were detected at elevated levels above the RIDEM Industrial/Commercial Direct Exposure Criteria (I/C DEC) in the former parking area (north of Buildings 20 and 26) and on the eastern side of Buildings 15

and 25. Total Petroleum Hydrocarbons (TPH) and other PAHs were also detected above I/C DEC in the former parking area. All the compounds detected are typical of urban impacts and are likely not associated with plant operations. These detections represent local impacts that will be addressed as part of this CMS.

Grab groundwater samples NP-GW1 and NP-GW2 had no detections of VOCs in groundwater.

While there was no indication of a release in and around the former office, lab and warehouse area (Buildings 15, 20, 25 and 26), soil gas results collected along the western side of Buildings 15 and 21 exceeded some EPA Vapor Intrusion Screening Levels for Soil Gas in residential areas. The compounds that exceed risk screening levels, chloroform and bromodichloromethane, are commonly related to drinking water treatment chemistry and are not deemed to be related to Site operations. Chloroform was not detected in groundwater samples collected from two groundwater grab sample locations in the vicinity of the Site buildings.

Sampling of soil vapor below and indoor air within the OWLA buildings in January 2014 indicate that chloroform and benzene are present in both soil vapor and indoor air at low levels though above the EPA stringent screening values. However, the detections in indoor air are within USEPA's target cumulative risk range of 1×10^{-6} to 1×10^{-4} and the total HI is below RIDEM/USEPA's target HI of 1, indicating that there is no unacceptable risk/hazard associated with inhalation of indoor air within the Site buildings. Chloroform and benzene may be associated with cleaning products (e.g., bleach) and/or laboratory uses where residual concentrations are slowly desorbing from building surfaces.

2.5.1 FPA Groundwater Characterization

The revised SRI report (AECOM Draft, 2014; Final 2016) provides the details of the data presentation and derivation of the CSM for the Site, where the CSM provides an explanation for the nature and extent of contamination observed, and it provides the basis to propose necessary and sufficient remedial action(s) to address potentially unacceptable risk to human health and the environment.

Since the completion of the revised SRI report, PDI data collection has been completed in areas of the FPA. The PDI data was collected after identifying elevated VOC concentrations in vadose zone soils within the SWMU 11 area (E-280 and E-300) where a historic toluene release was documented and/or localized impacts from the piping runs may have occurred. Four soil borings were advanced via Geoprobe direct push methods south of the elevated VOC concentration area. Soil was sampled from the ground surface into shallow to mid depth groundwater (to approximately 26 ft bgs) at SB-301, SB-302, SB-303, and SB-304 to determine whether VOC impacts are present in the vadose zone and/or groundwater via a pathway from upgradient shallow soil impacts to downgradient groundwater. Two soil samples were collected and analyzed for VOCs from each soil boring at intervals exhibiting high field screening levels of VOCs (based on PID readings). In addition to soil, each soil boring was completed with temporary piezometer monitoring points screened from 6 to 16 ft bgs and 16 to 26 ft bgs. Groundwater was sampled from each monitoring point and analyzed for VOCs. Procedures for soil and groundwater collection were consistent with those described in the Supplemental Remedial Investigation (SRI) Workplan (AECOM, June 2012).

What follows here are the elements of the CSM upon which this CMS is based. The hydrogeological attributes of the CSM are as follows:

- Groundwater is encountered at 6 to 10 ft bgs.
- The water table gently slopes toward the river (**Figures 4A and 4B**).

- The vertical gradient is generally downward across the Site indicating that groundwater recharge conditions prevail (**Figure 4A and 4B**).
- The natural discharge point for site-related groundwater is the Pawtuxet River, which is a gaining water body adjacent to the Site, as evidenced by the fact that the river stage is lower than the groundwater elevation (**Figure 4A and 4B**).
- The groundwater flow is affected by a bulkhead wall (sheet piling) that extends to a depth of 25 ft bgs, where groundwater is deflected downward under the wall as it migrates toward the river (**Figure 4A and 4B**).
- Hydraulic and water quality profiling conducted along the southern property boundary and along the bulkhead abutting the Pawtuxet river indicates that the intermediate “aquitard” is heterogeneous with permeable layers containing contaminant mass, and likely providing a conduit to flow and transport of Site COCs.

The nature and extent of contaminant mass in groundwater is described by the following CSM:

- Residual groundwater impacts are limited to the southwestern quadrant of the Production area, and they are associated with past plant operations that occurred primarily in Building 16. Building 16 was associated with a former sump leak. PDI data collected in September 2014 also show residual soil and groundwater impacts associated with SWMU 11 and potentially from portions of the piping run in the vicinity of SWMU 11.
- The impact observed is primarily composed of the five VOC COCs commonly used in the production process, identified in 1995 and assigned MPS, namely: 1,2-dichlorobenzene, chlorobenzene, 2-chlorotoluene, toluene, and total xylenes. **Figures 10A-J and Figures 11A-E** present the groundwater plumes in plan and cross-sectional views for each of the five site-specific COCs which have MPS defined.
- In addition to the 5 VOC COCs listed above, there is a sub-area where other VOCs are uniquely identified as exceeding the RIDEM GB criteria. These include: tetrachloroethene, vinyl chloride and benzene. These compounds are not detected in on-site soil at elevated concentrations and no likely source material based on past operational history. These non-MPS VOC detections are observed in groundwater only and at elevated concentrations adjacent to the river and the neighboring facility. It is possible that the source of these VOCs is off-site. Nevertheless, these compounds are generally collocated with one or more site-related COCs in excess of an MPS.
- The volume of aquifer impact is defined by any compound exceeding the MPS. Thus the remedial action target volume is defined by the MPS.
- The shallow VOC COC plume extends to the bulkhead wall. It is likely that these compounds/impacts have migrated along the permeable shallow aquifer/less permeable intermediate aquifer interface.
- Groundwater impacts are more extensive with depth (> 20 ft) due to a combination of influences: downward flow (general recharge conditions enhanced by the bulkhead), dispersion induced by aquifer heterogeneity, and historical remedial pumping [PW-120 screen 10 to 15 ft bgs and 30 to 40 ft bgs and PW-130 screen 7 to 17 ft bgs and 28 to 38 ft bgs]
- The intermediate aquifer zone (approximately 20-30+/- ft bgs) consists of heterogeneous low permeable materials with lenses of higher permeability that contain VOC COC impacts above the MPS.

- Water quality sampling of the aquifer on both the upland and river sides of the bulkhead wall shows VOC COC impacts above the MPS. Therefore, a completed exposure pathway is apparent.
- The nature and extent of COC impacts are consistent with the characterization of plant operations, the hydrogeology (i.e., aquifer heterogeneity and groundwater flow) and the location of potential VOC source material.
- PCBs were detected in upland groundwater within the VOC MPS exceedance zone. The only available standard for PCBs in groundwater is the RIDEM drinking water maximum contaminant level (MCL) of 0.5 ug/L. PCBs were detected in groundwater above the MCL in samples collected from MP-3I and MP-3S during July 2013. These wells were installed in 2012 as part of the AVE/AS pilot test. Where PCBs were detected in groundwater, one sample (MP-3I, 18-22 ft bgs) had an elevated turbidity (538 NTU) and a second sample (MP-3S, 5-13 ft bgs) had low turbidity (2.9 NTU). PCBs could be sorbed to soil particles or dissolved in water at low concentrations with co-solvents, or these detections may be due to carry down during well installation. PCB concentrations are not detected in groundwater in other parts of the upland area (MW-21S, MW-34D, MW-102D) and these PCB concentrations at MP-3 attenuate in groundwater as groundwater migrates to the river (MW-2S) and are not detected in other wells along the river (MW-31S, MW-31D, MW-29D, P-30D, P-35S). While PCBs exceeded the drinking-water standard at two upland locations (9 ug/L and 14.1 ug/L), the GB aquifer is not used for drinking water. Given this fact and the proposed remedial measures for PCB soil impacts (removal and capping) and MPS groundwater impacts (in-situ treatment) (**Figure 8**), these impacts do not require targeted remedial action.

2.5.2 FPA Soil Characterization

As detailed in the SRI Report (AECOM Draft, 2014; Final 2016) and outlined here, there are areas of residual PCB, TPH/SVOC, and VOC mass present in soil within the FPA:

- VOC mass potentially capable of impacting groundwater above the MPS was detected in vadose zone soils (2-6 feet bgs) collected in the southwest corner of the former Building 11 footprint, where the soil stabilization SVE IRM was implemented from 1997 to 2005 (see **Figures 10A-J, and Figure 11A-E** for location). Additional PDI data collected in September 2014 indicates that the vadose zone soils have impacted shallow and deep groundwater in this area.

The nature and extent of the residual PCB mass in soil within the FPA includes:

- PCB impacts associated with soil samples analyzed during the Supplemental RI appear to be related to spills or operational activities at Buildings 10 and 18, where transformers were once used, as well as potentially with a supply line or disposal line related to Building 11 operations. The general distribution across the FPA is consistent with mechanical mixing that likely occurred during plant demolition. These impacts are proximal to the PCB soil excavations that were conducted during the IRM (**Figure 3**).
- PCB grid sampling conducted during 2013/2014 fully characterized the extent of the PCB impacts located at the Site. While limited PCB impacts had been characterized and thought to have been remediated with IRM excavation events, several areas exceeding the 50 ppm MPS and 10 ppm RI DEM I/C and residential DEC remain. The areas with elevated PCB concentrations are illustrated on **Figure 9**.

2.5.3 OWLA Soil Characterization

Elevated TPH and SVOCs were identified above I/C DEC and/or R DEC in shallow soil sampled in the parking area to the north of the Site buildings and SVOCs above I/C DEC were detected east of the Site buildings. While these compounds were not identified as COCs for the Site, their nature and extent will be used to define necessary remediation and future land use options. The compounds and exceedances are illustrated on **Figure 12**. Several soil samples in the northern area were also analyzed for PCB (SB-128, SB-129, SB-144 through SB-149) and were less than 1 ppm.

2.5.4 Pawtuxet River Sediment

As discussed in Section 2.4.2, a sediment IRM was implemented in 1996 to address site-related impact to this medium (Sediment IRM Pawtuxet River, 1996). The IRM continues to rely on a clean sand cap to sequester deeper site-related impacts that remain. The last time the cap integrity was characterized was in 2011 after a 100 year flood event, and at that time the cap was shown to be intact and functioning as intended (AECOM, 2011).

2.6 Status of the FWWTA

The FWWTA property was sold in 2004, and since that time it has been used as a commercial landscaping business. As introduced previously, to date the USEPA has not issued a Statement of Basis and as such it remains part of this CMS.

A remedial investigation was conducted at the FWWTA from 1990 to 1995 and described in the RFI report (Ciba, 1995). Two SWMUs (10 and 12) were associated with the FWWTA, described in the RFI (Ciba, 1995) and are illustrated on **Figure 13**.

RFI soil data from the FWWTA was evaluated in a risk assessment submitted to and reviewed by USEPA (RFI, 1995). There were sporadic detections of two SVOCs, a pesticide (chlordane) and arsenic in soil in excess of the RIDEM I/C DEC, as shown in the following table. Except for chlordane which was utilized on-Site for pest control, these compounds were not considered site-related at the time of the RFI.

Table: FWWTA Shallow Soil Detections Exceeding I/C DEC

Compound	I/C DEC (ppm)	Concentration (ppm)	Sample Depth (ft bgs)	Frequency of Detection
Benzo(a)pyrene	0.8	3.6	0.5 – 2	5 of 18
Dibenz(a,h)anthracene	0.8	17	0.5 – 2	1 of 18
Chlordane	4.4	4.6 J	0.5 – 2	8 of 21
Chlordane	4.4	19 J	0 – 2	8 of 21
Arsenic	7.0	8.1 J	0.5 - 2	15 of 15
Arsenic	7.0	11.7	0.5 - 2	15 of 15
Arsenic	7.0	8.2	0.5 - 2	15 of 15
Arsenic	7.0	7.7 J	0.5 - 2	15 of 15
Arsenic	7.0	9.5 J	0.5 - 2	15 of 15
Arsenic	7.0	9.9	0.5 - 2	15 of 15

*Frequency of detection indicates how many soil samples in which the compound was detected, and any exceedances of I/C DEC are listed in the table (see **Figure 13** for location).

The risk assessment concluded that detected compounds identified as FWWTA compounds of potential concern (dieldrin, chlordane, 2,3,7,8-TCDF, bis(2-ethylhexyl)phthalate, PCBs) posed no unacceptable risk for an unrestricted future site use because the risk was within the USEPA target risk range of 1×10^{-4} and 1×10^{-6} and the total hazard index was less than 1.

In addition to the conclusion of the risk assessment for unrestricted use, there are development constraints on the property. **Figure 13** shows that the sporadic I/C DEC exceedances are within the 200-foot riverbank wetland zone, which precludes any development and soil management without RIDEM approval. Additional approval would likely be required by the municipality for work in the 100 year floodplain and depending on the size of any future project, RIDEM involvement may be necessary as well if the disturbance exceeds certain land area thresholds. These permit applications would require a stormwater management and sediment and erosion control plan, approval of which may offer a means to limit exposure to impacted soil. The property is currently zoned as commercial for office or neighborhood business (Cranston, RI Code of Ordinances, library.municode.com). Based on the limited risk and development constraints, the FWWTA soil does not warrant further action.

Groundwater sampling in the FWWTA (Ciba, 1995) was also evaluated in a risk assessment, which was submitted and reviewed by USEPA. The risk assessment concluded that compounds detected in groundwater posed no unacceptable risk for an unrestricted residential future site use. In addition, groundwater did not exceed any criterion listed in the Remediation Regulations. Therefore, the groundwater at the FWWTA property does not warrant further action.

3.0 Corrective Measures Objectives

Corrective Action Objectives (CAOs) provide the basis for remediation and summarize the remedial goals for corrective measures. CAOs were developed for the following areas:

1. Soil areas: Residual PCB impacts in the FPA and shallow soil in the OWLA (adjacent to buildings and in the former parking area);
2. Groundwater in the southern portion of the FPA;
3. Sediment in the Pawtuxet River adjacent to the FPA; and
4. Soil in the FWWTa.

Site-wide and media-specific CAOs are summarized below:

- *Site wide CAO*
 - Protection of human health from unacceptable exposure (unacceptable is defined as cancer risk greater than 1×10^{-4} and Hazard Index > 1) to environmental impacts at the Site.
 - Protection of the environment from exposure to impacts at the Site.
- *FPA CAOs*
 - Soil*
 - Ensure soil is remediated to a direct exposure level that is protective of human health for anticipated high occupancy, industrial, commercial and open space future uses.
 - Groundwater*
 - Maintain compliance with regulatory consent orders and RCRA Corrective Action.
 - Reduce groundwater impacts by addressing identified residual impacts acting as ongoing sources.
 - Reduce FPA groundwater impacts to below applicable standards as described in **Section 3.1**.
 - Reduce impacts to the Pawtuxet River sediment by treating groundwater transported in permeable pathways in the vicinity of the bulkhead wall, such that COC concentrations in shallow and deep groundwater potentially discharging to the river are below applicable criteria.
- *OWLA CAOs*
 - Soil*
 - Ensure soil is remediated to a direct exposure level that is protective of human health for industrial and commercial future uses.

- *River Sediment CAOs*
 - Ensure existing sediment cap integrity is protective of the environment through periodic monitoring.
 - *FWWTA CAOs*
- Soil*
- Ensure current and future land uses are consistent with historic risk evaluations, and future uses are protective of human health.

3.1 Media Specific Cleanup Standards

The Rhode Island Remediation Regulations (Remediation Regulations [RIDEM, 2011]) and site-specific Media Protection Standards (MPS) provide the applicable clean-up criteria for soil and groundwater at the properties under the RCRA Corrective Action program. The criteria to be applied for various media at the properties are discussed in the following sections.

3.1.1 FPA Soil

The Remediation Regulations contain numerical, default, criteria used to determine the need for remediation of soil associated with a release that are based on both the potential for human health impacts from direct exposure to contaminants in soil (direct exposure criteria) and on the potential for contaminants in the soil to have an adverse impact on groundwater (leachability).

Direct exposure criteria are specified based on the assumption that only industrial and certain commercial and open land use scenarios will be permitted. Because the property is currently zoned industrial/commercial, it is assumed herein that future site use will not include residential, and this condition will be incorporated into the property deed in the form of an ELUR.

Because groundwater is classified by RIDEM as GB (not for potable use), RIDEM GB leachability criteria for the protection of GB groundwater quality apply.

Table 3 summarizes applicable numeric criteria for Site COCs in soil.

Direct Exposure Criteria

I/C DEC will be applied to the FPA, which is currently zoned industrial. Because the I/C DEC will be applied, an ELUR must be executed to preclude future residential uses of the Production Area.

According to the Remediation Regulations, I/C DEC may be applied to a depth of at least 2 feet below ground surface for each hazardous substance in soil if all of the following conditions are met:

- a. The contaminated-site is currently limited to industrial/commercial activity. Open space provisions may be allowable under certain conditions with a clean 2 foot cap;
- b. Access to the property containing the contaminated-site is limited to individuals working at or temporarily visiting the subject parcel;
- c. The current and reasonably foreseeable future human exposure to soils at the contaminated-site is not expected to occur beyond a depth of 2 feet below ground surface; and

- d. An environmental land usage restriction consistent with Rule 8.09 (Institutional Controls) is in effect with respect to the property, or to the portion of the property containing the contaminated site; such an environmental land usage restriction shall ensure that the property or restricted portion thereof is not used for any residential activity in the future and that any future use of the property or restricted portion thereof is limited to industrial/commercial activity or RIDEM-supported open space.

Part (c) above is accommodated during future potential site redevelopment by the development and use of an appropriate soil management plan to be incorporated into an ELUR that specifies means and methods to protect worker health during and after construction. Part (d) must remain in place until further cleanup or evaluation is performed to meet more stringent criteria for unrestricted redevelopment. These conditions are incorporated into this CMS.

These criteria are for comparison to soil data, and **Table 3** provides the I/C DEC for the applicable site soil COCs (i.e., PCBs).

Leachability Criteria

Because the Production Area is located in a GB groundwater area, the GB leachability criteria, or equivalent as defined in the Remediation Regulations, apply. **Table 3** provides the relevant criteria for the applicable site soil COCs (i.e., PCBs).

Site-Specific Media Protection Standards (MPS)

Site-specific soil MPS were developed for the Production Area soil in the RFI (Ciba, 1995). A Public Health and Environmental Risk Evaluation (PHERE) was performed (Ciba Corporation, 1995), and no unacceptable human or ecological health risk was found for soils. While this was the case at the time, the site-specific PCB MPS for the Production Area soil was set at 50 ppm based on consideration of a future outdoor worker for an industrial or commercial land-use scenario. The site-specific MPS is compared to current federal and state rules governing PCB cleanup. Specifically, under the Toxic Substance and Control Act (TSCA), 40 CFR 761.61(a)(4), the low occupancy¹ criteria is 50 ppm if the site is fenced and marked. Alternately, removal of all PCBs in soil greater than 10 ppm and a cap over soil that contains greater than 1 ppm would allow a high occupancy Site re-use¹. Finally, an unrestricted use scenario is allowed with no capping requirement if PCBs are remediated to a level less than 1 ppm. The Rhode Island (RI) I/C DEC rules for PCBs in soil include removal of all PCBs greater than 10 ppm and placement of a 2 ft soil cap to support a high-occupancy, industrial/commercial future use scenario, or RIDEM-supported open space. The RIDEM requirements allow for the scenario evaluated herein consisting of the use of the 2 ft soil cap over soil with less than 10 ppm PCBs. An unrestricted use scenario was also considered to provide greater future use flexibility. PCBs must be remediated to a level less than 1 ppm in the unrestricted use scenario.

Caps used as remedial measures under TSCA 40 CFR 761.61(a)(7) are required to meet permeability, sieve, liquid limit and plasticity requirements. Variation from these requirements will

¹ High occupancy refers to areas where people spend significant time, 840 or more hours per year without dermal or respiratory protection (e.g. schools, residences).

require approval from EPA. In areas where PCBs will remain on-site at concentrations between 1 and 10 ppm, the RIDEM remediation regulations require that contact with such soil be eliminated by rendering it inaccessible beneath 2 ft of clean soil with no permeability requirement as 10 ppm meets the RIDEM GB leachability requirement. A clean soil cap of 2 ft also meets the minimum thickness requirements (10 inches) required by TSCA 40 CFR 761.61(a)(7). This RIDEM-based measure to render the soil inaccessible is an effective means of compliance with the DEC when the soil cap is maintained through implementation of an ELUR that details the configuration of the inaccessible soil area and requires that the cover be maintained. Therefore, a RIDEM cap is considered a feasible alternative to that required under TSCA 40 CFR 761.61(a)(7).

3.1.2 FPA Groundwater

Site-related groundwater is classified by the RIDEM as GB, which is not suitable for use as a current or potential source of drinking water. The Remediation Regulations contain numerical, default criteria for contaminated GB groundwater associated with a release area. The criteria are established to be protective of human health (from contaminants that may volatilize from contaminated groundwater) and the environment (from contaminants that may adversely affect surface water resources). Additional information on groundwater criteria is presented in the following sections. **Table 4** summarizes applicable numeric criteria for Site COCs in groundwater.

GB Groundwater Objectives

The Remediation Regulations specify criteria for the protection of groundwater in a GB groundwater area. As discussed in Section 2.5.1, chlorinated ethenes and benzene have been collocated with Site COCs in groundwater. These compounds will thus be addressed with the remedy selected.

Site-Specific Media Protection Standards (MPS)

The Pawtuxet River Corrective Measures Study (Woodward-Clyde, 1996) presented MPS for site-specific volatile organic compounds (VOCs) in groundwater at the Production Area property: toluene (1,700 ppb), 2-chlorotoluene (1,500 ppb), 1,2-dichlorobenzene (94 ppb), chlorobenzene (1,700 ppb), and total xylenes (38 ppb). The MPS for these COCs, except toluene, were based on benthic invertebrate Toxicity Reference Values (TRVs) and developed to be protective of benthic organisms as site-related groundwater discharges to the river. For toluene, the MPS was based on the RI GB Groundwater Objective because it was a lower value, and thus, more protective. The MPS for total xylenes was later corrected to 76 ppb in the April 1998 Groundwater Sampling Report submitted to USEPA in August 1998. The report states that the revision, based on a mis-reporting of 38 ppb in the original Pawtuxet River CMS, was approved by USEPA. These groundwater MPS will be applied to the Production Area property.

3.1.3 OWLA Soil

As discussed in Section 2.5, the OWLA was not identified as an AOC, 2013 – 2014, sampling by BASF detected sporadic PAH and SVOC compounds that exceed the RIDEM I/C and R DEC. As such, for any future land use scenario these soils will need to be addressed by eliminating the direct potential exposure pathway (removal and/or clean cover) and imposition of an ELUR that will preclude future residential use.

3.1.4 Pawtuxet River Sediment

As part of the Production Area IRM program implemented in the 1995 – 1996 time-frame, a voluntary sediment IRM was conducted, where over 2,225 tons of visually contaminated river sediment from the Former Cofferdam were excavated and replaced with a clean sand cap (Woodward-Clyde, 1996).

A major flooding event occurred during the spring of 2010, and at that time the USEPA requested that BASF re-sample the sediment cap to ensure that it is functioning as intended. In 2011 BASF took samples of the capped area and found it to be functioning as intended with the coarse sand cap still in place (AECOM, 2011).

This media is included in the CMS in order to specify a periodic monitoring program for the emplaced sand cap in the Pawtuxet River. **Table 5** outlines the periodic monitoring strategy for the cap and sediment.

3.1.5 FWWTA Soil

As discussed in Section 2.6, soil sampling in the FWWTA was evaluated in a risk assessment submitted to and reviewed by USEPA (RFI, 1995). The risk assessment concluded that compounds detected in soil posed no unacceptable risk for an unrestricted future site use because the risk was within the USEPA target risk range of 1×10^{-4} and 1×10^{-6} . This property is zoned as commercial for office or neighborhood business (Cranston, RI Code of Ordinances, library.municode.com) which is a more conservative re-use scenario than the risk assessment assumption of an unrestricted future use. Therefore, soil criteria will not need to be considered for the FWWTA. Based on redevelopment constraints due to the 200 ft Riverbank Wetland boundary and limited exposure risk, no further action is warranted for FWWTA soil.

3.2 Compliance Points

3.2.1 Soil

Soil compliance is point-by point, where the remedy must address all impacts above some standard either by removal, capping or imposing institutional controls. Post-remedy controls must be verified with an appropriate sampling plan. Post-excavation compliance sampling will be conducted as the soil remedy is implemented in the FPA. The compliance sampling program will be described in the future soil remediation design.

3.2.2 Groundwater

Site-related groundwater from the FPA eventually discharges to the Pawtuxet River. The MPS defined for the FPA were derived to be protective of environmental receptors, in particular benthic organisms. Thus, the compliance points for groundwater associated with the Production Area will be located between the Site and the river. Based on where the groundwater plume is located as it migrates towards the Pawtuxet River, the proposed wells where compliance with the MPS is needed for the Production Area are listed in the following table and shown on **Figure 14**:

Groundwater

MW-32S/D (Proposed)

MW-31S/31D

P-30D

MW-29D

3.2.3 Sediment

The sediment area that comprises the former cofferdam area, adjacent to the Production Area, will be addressed through periodic monitoring to confirm the presence of the IRM engineered control (i.e., sand cap). The area of the cap is depicted on **Figure 15**. A sediment cap monitoring program will be developed and submitted under separate cover.

3.3 Description of Remedial Alternatives Considered

3.3.1 FPA Soil

Remediation area limits for FPA soil vary based on the nature and extent of PCB impacts and potential future Site use scenarios which are presented below. In addition there are impediments to excavation in the form of foundations, footings and concrete rubble-filled basements. Soil volumes and areas presented below are based on existing data and provide a basis for alternative evaluation as potential remedial scenarios. Actual parameters may change based on either a pre-design investigation or post-excavation verification sampling, which may change the total estimated volumes for excavation, disposal or reuse in each scenario presented.

Low Occupancy Reuse Scenario - >50 PPM PCBs

The PCB MPS for the FPA soil is set at 50 ppm based on consideration of an outdoor worker for an industrial or commercial land-use. This cleanup level would allow a low occupancy Site re-use under current TSCA regulations. The low occupancy criteria is 50 ppm if the site is fenced and marked. Depth and areas associated with remediation of this potential future use scenario are shown on **Figure A-1**. The following aspects are associated with an excavation and capping remedy:

- Excavation/disposal: Several discrete areas of soil with PCBs > 50 ppm up to 6 ft deep, totaling 1,170 cubic yards (CY). In addition, as discussed in Section 2.5, the local VOC impacts associated with sample locations E300 and E280 will also be removed in this scenario (approximately 30 CY);
- Excavation/on-site reuse/consolidation/cap preparation of soil with PCBs > 1 ppm from the top 2 ft outside of the area to be capped (1,230 CY for on-site reuse);
- Clean cap material: Covers the Site with a 2 ft thick soil cap (5350 CY); and
- An ELUR and soil management plan are required for the FPA to ensure land use restrictions and cap maintenance.

The areas/volumes above involve discrete removal of soils with greater than 50 ppm PCBs. Details of area and depth calculations are included in **Appendix B**. A 2 ft clean soil cap would be utilized across approximately 3.1 acres of the FPA, but will require cap preparation excavations since a portion of the Site is located within the 100 year flood plain and raising the grade within the flood plain

is not appropriate. The exact location and quantities of the cap over remaining material left on-Site would be determined during the design phase of work.

High Occupancy Reuse Scenario - >10 PPM PCBs

Removal of PCBs in soil greater than 10 ppm and a cap over soil that contains greater than 1 ppm and less than 10 ppm PCBs would allow a high occupancy Site re-use. Rhode Island (RI) I/C DEC limit PCBs in soil to a maximum of 10 ppm, with a 2 ft clean soil cap. Depth and areas associated with remediation of this potential future use scenario are shown on **Figure A-2**. The following aspects are associated with an excavation and capping remedy:

- Excavation/ off-site disposal: 6,300 CY from discrete areas of soil with PCBs >10 ppm to depths of up to 7 ft deep, this includes approximately 30 CY of residual VOC-impacted soil;
- Excavation/on-site reuse/consolidation/cap preparation of soil with PCBs >1 ppm from the top 2 ft outside the area to be capped: 3,800 CY (for on-site reuse);
- Backfill materials: 7,550 CY;
- Clean cap material: Covers the Site with a 2 ft thick soil cap (1,550 CY); and
- An ELUR and soil management plan are required for the FPA to ensure land use restrictions and cap maintenance.

The areas/volumes above involve removal of soils with greater than 10 ppm PCBs. Details of area and depth calculations are included in **Appendix B**. A 2 ft clean soil cap would be utilized across approximately 0.5 acres of the former Production Area, but will require cap preparation excavations since a portion of the Site is located within the 100 year flood plain and raising the grade within the flood plain is not appropriate. However, the exact location and quantities of the soil removed, reused, and the cap over remaining material left on-Site would be determined during the design phase of work.

Unrestricted Use Scenario - >1 PPM PCBs

An unrestricted use scenario was also considered to provide greater future use flexibility. PCBs must be remediated to a level less than 1 ppm in this case. Depth and areas associated with remediation of this potential future use scenario are shown on **Figure A-3**. The following aspects are associated with an excavation and capping remedy:

- Excavate: 11,000 CY from discrete areas of soil with PCBs >1 ppm to depths of up to 7 ft deep, this includes approximately 30 CY of residual VOC-impacted soil;
- Dispose: 16,750 CY;
- Re-use: 900 CY; and
- Backfill materials: 13,200 CY.

The areas/volumes above involve removal of soils with greater than 1 ppm PCBs for an unrestricted future use scenario. Details of area and depth calculations are included in **Appendix B**. No capping or ELUR and soil management plan would be required.

3.3.2 OWLA Soil

Remediation area limits for OWLA soil vary based on the nature and extent of PAH and SVOC impacts in excess of the RIDEM I/C DEC to support a nonresidential reuse scenario.

East of Site Buildings

Discrete areas of impacted soil will be addressed as follows on the east side of the Site buildings to prevent exposure to surface soil and attain compliance with I/C DEC:

- Surface soil (6 inches or greater in depth) will be removed;
- A witness marker barrier (geotextile and orange snow fence) will be laid down within the excavation;
- Clean soil will be imported and placed in the excavation;
- Grass and shrubs will be planted over the disturbed area;
- A fence may be installed around the area;
- An ELUR restricting future site use will be utilized; and
- A soil management plan will be developed to include: procedures for soil characterization, soil handling, storage/stockpile management, documentation of soil disposal, and a description of any institutional controls in place.

An outline of the area to be addressed is shown on **Figure A-4**.

Three Parcels North of Site Buildings

Three parcels are located north of the former laboratory and warehouse buildings that were historically used as parking areas for the facility. These three parcels are located adjacent to residential properties. Because the soil below the pavement is impacted with PAH and SVOC above the I/C DEC, to comply with the Remedial Regulations an ELUR will be required that specifies future non-residential use and maintenance of the pavement surface. In addition, a soil management plan will be included to address the scenario where the pavement is removed. Targeted excavation may be utilized to address soil containing I/C DEC exceedances in this area. The area to be addressed is shown on **Figure A-4**.

3.3.3 FPA Groundwater

Remediation area limits were selected to achieve the MPS criteria of Site COCs identified as discharging to the Pawtuxet River. Additional contaminants exceeding GB groundwater criteria are located within the COC treatment area and will thus also be addressed.

The extent of groundwater requiring remediation was evaluated using plans of the Site, groundwater flow mapping, groundwater analytical data and cross-sections of subsurface conditions. Cross-sections were constructed parallel and perpendicular to the approximate axis in the direction of groundwater flow. The horizontal extent of VOC impacts to groundwater is depicted on **Figure 8**. Areas highlighted on the figure represent MPS exceedances. In addition to illustrating the distribution of MPS exceedances, the conceptual groundwater remedial approach is depicted on **Figure 16**.

The available data were integrated and combined to identify the appropriate treatment zones, i.e., permeable media with COC impact. Cross-section A – A' (parallel to plume axis) is included as **Figure 17**. Electrical resistivity data was contoured and plotted on this cross section as is the MPS exceedances distribution. Electrical resistivity in this aquifer is correlated with more permeable materials, because fine-grained materials like silts/clays are generally more electrically conductive (or, have lower electrical resistivity). **Figure 17** is illustrative of the highly heterogeneous subsurface.

The stratigraphic and groundwater analytical data were evaluated to determine the volumetric zones where remediation would be required and most effective at addressing groundwater impacts and achieving the remedial objective. **Figure 17** includes the treatment intervals that result from this evaluation.

Because of the depth of impact and the presence of subsurface infrastructure left in place during plant demolition (i.e., foundations), only in-situ contaminant mass destruction technologies or groundwater containment are feasible alternatives.

The mass destruction technologies include in-situ biotic degradation and in-situ abiotic chemical oxidation (see Section 4.2.2). Active treatment will focus on breaking the transport pathway from upland FPA groundwater reaching the Pawtuxet River sediments and surface water and removing residual source material in upland portions of the FPA.

3.3.4 Pawtuxet River Sediment

The former cofferdam area within the Pawtuxet River that was capped during a historic IRM represents the limits considered for a periodic monitoring program.

3.3.5 FWWTA

The FWWTA has sporadic I/C DEC exceedances of several PAHs, a pesticide (chlordane) and arsenic (a naturally occurring metal). These detections are located within 200' of a wetland bank, a condition that precludes land development and soil management without RIDEM approval and while not explicitly an ELUR, does give some jurisdiction to RIDEM over development. Further, depending on the size of a future development scenario, additional municipal/RIDEM permitting may be required to address stormwater management and sedimentation and erosion controls during construction because portions of the FWWTA are within the 100 year floodplain and designated floodway of the Pawtuxet River. This condition, coupled with the conclusion of a human health risk assessment that supported unrestricted land use, is consistent with a no further action scenario.

4.0 Screening of Technologies

4.1 Screening Criteria

An initial list of potential technologies was screened for impacted media at the Site. Criteria used to screen technologies include site conditions, contaminant characteristics, and technology characteristics. A description of each criterion is provided.

- **Site conditions:** Site data was reviewed to identify conditions that may limit or promote the use of certain technologies. Technologies whose use is clearly precluded by site characteristics were eliminated from further consideration.
- **Contaminant characteristics:** Identification of contaminant characteristics that limit the effectiveness or feasibility of technologies is an important part of the screening process. Technologies clearly limited by these contaminant characteristics were eliminated from consideration. Contaminant characteristics particularly affect the feasibility of in situ methods, direct treatment methods, and land disposal (on/off site).
- **Technology limitations:** During the screening process, the level of technology development, the performance record, and the inherent construction, operation, and maintenance limitations were identified for each technology considered. Technologies that are unreliable, perform poorly, or are not fully demonstrated for the Site conditions and COCs were eliminated in the screening process.

Technologies which are deemed impracticable for use at the Site based on site conditions and contaminant mixtures were not retained for further evaluation.

4.2 FPA Remedial Technologies

The screening of the soil and groundwater technologies considered for the Production Area parcel is discussed below.

4.2.1 FPA Soil Technology Screening

Soil in the FPA contains elevated concentrations of total PCBs that exceed the RIDEM I/C DEC concentration of 10 ppm as well as isolated locations that exceed Toxic Substances Control Act (TSCA) limits and the site-specific MPS of 50 ppm. In addition, sporadic detections of semi-volatile organic compounds (SVOCs) and VOCs at concentrations that exceed RIDEM I/C DEC are present. Remediation of impacted soil is evaluated in the CMS. Alternatives under consideration are: No Action, Institutional and Engineering Controls, ELUR, Engineered Control (Cap), Excavation and Off-Site Disposal. Combinations of these alternatives are evaluated. Initial screening results for soil are included in **Table 6**. Figures showing conceptual remedial designs, soil volume calculations, and costs/assumptions in implementation are included in **Appendix A, Appendix B, and Appendix C** respectively. Retained technologies are further described in the following sections.

4.2.1.1 No Action

The no action technology serves as a baseline against which other corrective measure technologies can be compared. Under this alternative, no remedial action would be conducted. The contaminants

are left in place without implementing any containment, removal, treatment, or other mitigating actions. The no action alternative would not include institutional or engineered controls to prevent access to surface or subsurface soils. No ongoing monitoring is included with this alternative.

4.2.1.2 Institutional Controls

Institutional controls are used to reduce risk of human exposure and/or further impacts to the environment by restricting site use and/or rendering impacts inaccessible or environmentally isolated.

Land use restrictions are means of enforcing a restriction on the former Production Area that limits exposure to impacted materials and prevents actions that would interfere with the remedial program. The former Production Area is zoned industrial/commercial and currently is idle. The former Production Area will continue to meet the requirements of industrial-commercial land use in the future, and an ELUR limiting future use to industrial-commercial use will be recorded, unless further cleanup or evaluation is performed to meet more stringent criteria for residential re-development. There are three general types of ELURs for soil, which are described below:

- Limits future uses of the former Production Area to industrial-commercial;
- Prohibits disturbance or exposure to inaccessible soils (e.g. impacted soil below an adequate separation layer); and
- Protects any engineered controls that prevent infiltration of water through impacted soil.

The three ELURs allow for access to the former Production Area to implement required monitoring.

In some cases, the ICs are used in conjunction with a containment mechanism (e.g. capping/engineered control) to address applicable criteria. ICs were retained for evaluation.

4.2.1.3 Engineered Controls

Engineered controls are used to reduce risk of human exposure and/or further impacts to the environment by rendering impacts inaccessible or environmentally isolated.

The existing engineering controls at the Production Area consist of perimeter fencing around the Site to prevent unauthorized access, and paved areas which inhibit direct contact with underlying soil.

An engineered control cap prevents direct exposure to the contaminants and/or prevent migration of the contaminant. Engineered control caps include containment technologies consisting of covers and/or impermeable liners. Implementation of this remedial approach requires:

- Assessment of hydrogeologic setting (e.g., proximity to wetlands and flood hazard areas);
- Permitting;
- ELUR;
- Long-term monitoring and inspection/maintenance plans; and
- Annual reporting.

The use of engineered controls utilizing covers and/or impermeable liners to address DEC exceedances was retained for evaluation.

4.2.1.4 Excavation and Offsite Disposal, Containment or Reuse

Excavation of impacted soils will be evaluated to address I/C DEC exceedances in the former Production Area for PCBs and SVOCs. The following options were retained for evaluation:

- Excavation and off-site disposal; and
- Excavation and on-site consolidation/reuse beneath an engineered control.

Regarding implementability, recall that when the plant was demolished the subsurface structures were left in place including extensive foundations, footings and pilings. These concrete structures will to some extent limit excavation.

4.2.2 FPA Groundwater Technologies

The alternatives described in this section are applicable to FPA groundwater.

Several technologies presented in the Stabilization Report (Woodward-Clyde, 1996) have already been constructed in the former Production Area. These technologies include a soil vapor extraction (SVE) system, extraction wells (hydraulic control system), and technologies used to treat extracted groundwater. The SVE system was constructed and operated to treat a toluene spill; it was shut down in 2005. The groundwater extraction and treatment system operated from 1996 to 2010 when long-term monitoring data showed aquifer restoration complete except for a recalcitrant area that was the subject of extensive remedial investigation (AECOM, 2012), and the recalcitrant area is the subject of this CMS.

Initial technology screening results for groundwater are included in **Table 7**. Figures showing conceptual remedial designs and costs and assumptions in implementation are included in **Appendix D** and **Appendix E**, respectively. Retained technologies are further described in the following sections.

4.2.2.1 No Action

No action provides a comparative baseline against which other corrective measure technologies can be compared. Under this alternative, no remedial action would be conducted. The contaminants are left in place without implementing any containment, removal, treatment, or other mitigating actions. All groundwater monitoring, groundwater extraction, and reporting activities would cease. Natural processes such as biodegradation, dilution, and attenuation would continue, but these processes would not be monitored.

4.2.2.2 Institutional and Engineering Controls

Institutional controls are a means of enforcing a restriction on the Site that limits exposure to impacted materials and prevents actions that would interfere with the remedial program. The Site is currently idle. The Site will continue to meet the requirements of industrial-commercial site use; however, an ELUR limiting future use to industrial-commercial use has not yet been recorded for the Site. An ELUR limiting site use to industrial-commercial is anticipated, unless further cleanup or evaluation is performed to meet more stringent criteria for residential re-development.

Engineering controls consist of means to physically isolate residual source areas in soils and the impacted portions of the aquifer. A sheet pile wall installation around impacted soil and groundwater was considered in this alternative.

4.2.2.3 Monitored Natural Attenuation

Monitored Natural Attenuation (MNA) is a technology that relies upon the reduction of contaminant concentrations in groundwater resulting from the combined effect of dispersion, diffusion, volatilization, sorption, abiotic degradation, and biodegradation. The combined effect of these processes results in a concentration reduction over space and time that will result in a restorative trend. MNA is a plausible corrective measure that also involves groundwater monitoring to confirm the effectiveness of the natural attenuation and to quantify the reductions. MNA may be incorporated as a component of the remedial approaches outlined below.

4.2.2.4 In Situ Treatment Technologies

Initial considerations were made for implementability of a plume-wide versus barrier approach for in situ treatment technologies. There are several site attributes that affect implementability. First, the recalcitrant groundwater impact zone that is the focus of the remedial action considered here is associated with contaminant releases that occurred more than 40 years ago. In addition, a soil vapor extraction (SVE) system operated in the SWMU 11 area as an IRM for 8 years to address a toluene pipeline release and a groundwater capture system was operated for 12 years as an IRM to address this impact by controlling groundwater discharge to river sediments and surface water (the identified receptor pathway). Locally, elevated concentrations of site COCs are present in a residual source zone in upland portions of the FPA. As the data support, in downgradient locations these conditions combine to result in the delineated recalcitrant mass occurring primarily as adsorbed and dissolved phase adjacent to and within the low conductivity aquifer material (silt). This mass is slowly back diffusing into the more permeable units to create the groundwater plume that is observed to be approaching the river today. An in-situ remedial action that attempts to address this entrained mass through amendment emplacement will need to be applied on a fine spatial scale owing to the low conductivity material characterizing the aquifer.

In addition to this fate and transport characterization attribute, one needs to consider a second key Site attribute, where the impact area is below and around former building foundations and footings and pilings that remain in place. These extensive concrete structures will significantly limit the ability to apply necessary amendments at the appropriate scale in terms of required spatial distribution and volume acceptance for a plume-wide approach.

Given these attributes, a barrier approach was carried forth as the most feasible treatment application for breaking the transport pathway of groundwater to the Pawtuxet River. Where feasible, the selected in situ treatment will also attempt to address upland source and plume areas through a combination of technologies including excavation as part of the soil remedy and chemical oxidation.

Summary of Pre-Design Investigation and Bench Scale Test Activities

Several tasks were implemented after completion of the CMS Work Plan (AECOM, 2014) to further identify and select an appropriate in situ remedy and strategy for addressing FPA groundwater. First, PDI soil borings were advanced during September 2014, and second, geologic materials were collected for a bench-scale test to evaluate aerobic versus anaerobic biodegradation. Both efforts were completed in collaboration with and approval by EPA and the bench-scale test was discussed as a step for identifying an appropriate remedial technology for groundwater in the CMS Work Plan (AECOM, 2014). During the PDI effort, soil and groundwater were sampled from four discrete intervals between the area where elevated VOCs were identified during PCB sampling by field screening with a PID in soil (E280, E300 grid points) and the downgradient groundwater plume (see **Figures 10A-J, 11A-E, and 16** for sampling locations). The purpose of these four locations was to investigate

potential impacts to transition/vadose zone soils where the shallow VOC impacts upgradient may have entered the shallow/intermediate aquifer. **Figures 10A-J, 11A-E, and 16** provide plume maps that incorporate these data, as updated from those presented in the revised SRI (AECOM Draft, 2014; Final 2016). The PDI data are provided in **Appendix F**. Descriptions of the sample depth intervals are provided in Section 2.5.1.

In addition to PDI activities, a groundwater remediation bench-scale test was performed to compare two candidate in situ remedial alternatives for VOC-impacted groundwater: aerobic and anaerobic enhanced biodegradation. The resulting report is provided in **Appendix F**. Soil and groundwater were collected from areas where groundwater impacts have historically been found to be significant (e.g., MP-3IS) to provide the subcontracted laboratory with the materials needed to conduct the proposed bench-scale tests. Of the evaluated treatments, the aerobic microcosms showed the most rapid decrease in COC concentrations. Corresponding plots of chlorinated compound concentration trends are presented in **Appendix F**. The rapid rates of aromatic COC degradation are consistent with the literature, however the degradation rates for chlorinated ethenes (PCE, TCE, DCE, VC) are potentially a laboratory artifact of the low starting concentrations near the method detection limit, and may not be indicative of any true transformation that may have occurred in the lab, or that might occur in the field.

During the development of the CMS Work Plan (AECOM, 2014), in situ chemical reduction (ISCR) and enhanced microbial reduction was retained as an alternative. However, it was subsequently screened out based on the outcome of the bench scale test that was performed after its publication (see **Appendix F**). While this technology did reduce some concentrations of Site COCs, the results indicated that ISCR and enhanced microbial reduction is not nearly as effective as aerobic biodegradation and had slower kinetics for treatment. Therefore, it is not considered an appropriate technology for FPA groundwater. Results of the bench scale test are included in **Appendix F**.

The following in situ treatment technologies were retained during the screening process for impacted groundwater.

In Situ Chemical Oxidation

In situ chemical oxidation (ISCO) remediates contaminants by incorporating them into oxidation reactions. Chemical oxidants are injected/sparged into the aquifer, which chemically oxidize the COCs in the source and plume. Bench scale tests and a pilot study may be warranted to optimize injection/sparge locations, rates, and volumes of ISCO compounds.

In Situ Aerobic Biodegradation

Natural aerobic microbial processes are enhanced through the introduction of oxygen or introduction of microbial populations (bioaugmentation) via injection wells to reduce concentrations of VOCs by aerobic biodegradation processes.

A bench scale test was performed from September 2014 to July 2015. The objective of the bench scale test was to compare the effectiveness of aerobic versus anaerobic biodegradation/chemical reduction of Site COCs. This technology had favorable results for reducing concentrations of Site COCs, identifying aerobic biodegradation as an effective means of treatment at the Site. Results of the bench scale test are included in **Appendix F**.

4.2.2.5 Hydraulic Control System (Groundwater Pump & Treat System)

From 1996 to 2010 Ciba operated a groundwater extraction and treatment system to hydraulically control, both horizontally and vertically, impacted groundwater and prevent off site migration of former Production Area-related impacted groundwater. Extracted water was treated on the property and discharged to the municipal treatment works. This alternative consists of repairing and restarting the existing system.

4.3 OWLA

As discussed in Sections 2.5, 3.1.3 and 3.3.2, while this area was not considered an AOC during the RFI, sampling conducted by BASF from 2012 to 2014 determined that there are sporadic residual soil impacts of PAH and SVOC that are indicative of general industrial use and development and that are in excess of the I/C DEC. As presented in Section 3.3.2, to meet the requirements of the Remedial Regulations the preferred remedy for these impacts is to remove and/or cap the impacted soils and implement an ELUR to preclude future residential use.

4.4 Production Area Pawtuxet River Sediments

Several technologies presented in the Stabilization Report (Woodward-Clyde, 1996) have already been constructed in the Production Area. The technologies that were identified to be protective of sediment and river quality include sediment excavation, disposal, capping, and extraction wells (hydraulic control system) for hydraulic control of on-site groundwater from migrating into the river. Sediment excavation, disposal, and capping was completed during a Sediment IRM in 1996 as well as an additional Sediment IRM in 2012. The groundwater extraction and treatment system operated from 1996 to 2010 when long-term monitoring data showed aquifer restoration was complete except for a recalcitrant area. The recalcitrant area was the subject of extensive remedial investigation (AECOM, 2012), and it is a subject of this CMS. Because the IRM is functioning as intended, this CMS considers only periodic sediment sand cap monitoring to confirm its integrity.

4.5 FWWTA Technologies

The FWWTA was used as a waste water treatment facility for process water generated from the Production Area. In 2004, Ciba sold the property and its current use is a landscaping operation. The property is currently zoned for commercial use.

FWWTA soil and groundwater were characterized in the RFI (Ciba, 1995) and the impacts were found to be within the acceptable USEPA target risk range for unrestricted future use (see Section 2.6). While there are no compounds that exceed the RIDEM's GB groundwater criteria, there were two samples collected in 1995 that detected the pesticide gamma-chlordane in excess of the RIDEM I/C DEC. Specifically, chlordane was detected at an estimated value of 19 ppm and 4.6 ppm in two shallow soil locations which exceeds the RIDEM I/C DEC criteria of 4.4 ppm. Though exceeding criteria, these concentrations are representative of less than the mean concentration range of residues (22 ppm - 2,540 ppm) that are around home foundations that were treated with chlordane as a pesticide (<http://www.epa.gov/ttn/atw/hlthef/chlordan.html>), and it is thus considered not site-related.

Based on the discussion above (here and Sections 2.6, 3.1.5 and 3.3.5), the CMS report will evaluate a No Further Action alternative for the FWWTA. Institutional controls in the form of an ELUR were initially carried forth, but the property is no longer under the control of BASF, and therefore it is not feasible to impose future use restrictions as the owner must comply. Initial screening results for the WFWTA are included in **Table 8**. No Action is further described in the following section.

4.5.1 No Action

The no action technology serves as a baseline against which other corrective measure technologies can be compared. Under this alternative, no remedial action would be conducted. The contaminants are left in place without implementing any containment, removal, treatment, or other mitigating actions. In addition, the no action alternative would not include the imposition of additional institutional or engineered controls to prevent access to surface or subsurface soils. The 200 ft Riverbank Wetland boundary is established and prevents development and soil management without RIDEM approval. Finally, no ongoing monitoring is included with this alternative.

4.5.2 ELUR

Institutional controls are means of enforcing a restriction on the FWWTA that limits exposure to potentially impacted soils. The FWWTA is zoned for commercial use and currently is used as a landscaping operation. While this alternative was initially retained, the Site was sold in 2004, and BASF no longer controls future land use, therefore implementing an ELUR is not feasible as the current landowner must comply.

5.0 Development and Detailed Analysis of Corrective Measure Alternatives

This section summarizes the evaluation of retained corrective measure alternatives according to RCRA-designated performance standards. Each alternative was evaluated based on the ability to achieve three primary performance standards and six secondary balancing factors. These are the generic standards by which corrective measures are evaluated, and they apply to all media. At the conclusion of the detailed analysis of alternatives, selected corrective measure alternatives are identified.

5.1 Detailed Evaluation Criteria

Corrective measure alternatives selected for detailed analysis were evaluated according to the following performance standards:

- Primary Performance Standards, including:
 - Overall protection of human health and the environment
 - Attain media cleanup standards
 - Control the sources of releases
- Balancing factors (used to further evaluate alternatives meeting all three primary performance standards)
 - Long-term reliability and effectiveness
 - Reduction in the toxicity, mobility, or volume of wastes
 - Short-term effectiveness
 - Implementability and environmental footprint
 - Cost
 - Federal, State and community acceptance

Each of these evaluation factors is discussed briefly below.

5.1.1 Overall Protection of Human Health and the Environment

Corrective measures must be protective of human health and the environment. Alternatives may include those remedies that are needed to be protective of, but not directly related to, media cleanup, source area control, or management of contaminants. Each alternative was assessed to determine whether it can (1) adequately protect human health and the environment, in both short- and long-term time frames, from unacceptable risks posed by hazardous substances, pollutants, or contaminants and (2) eliminate, reduce, or control exposures to established remediation criteria.

5.1.2 Attain Media Cleanup Standards

Corrective measures were evaluated against the effectiveness of attaining media-specific corrective action objectives, which were derived from existing state and federal regulations, background levels, or alternative risk-based target cleanup levels. The media cleanup goals for an alternative often play a large role in determining the technical approaches of the alternative. In some cases, certain technical aspects of the alternative, such as the practical capabilities of technologies, may influence the media cleanup goals to be established. Each alternative was assessed to determine whether it would attain the treatment goals and protection standards established for the site media.

5.1.3 Control the Sources of Releases

A critical objective of any alternative is to reduce further environmental degradation by controlling or eliminating further releases that may pose a threat to human health and the environment. Unless source control measures are undertaken, efforts to clean up releases may be ineffective or, at best, will essentially involve a perpetual cleanup. Therefore, an effective source area control program is essential to ensure the long-term effectiveness and protectiveness of the corrective measure.

5.1.4 Long-Term Reliability and Effectiveness

Demonstrated and expected reliability is a way of assessing the risk and effect of remedy failure. Considerations include whether the technology or a combination of technologies have been used effectively under analogous site conditions, whether failure of any one technology in the alternative would have an immediate impact on receptors, and whether the alternative would have the flexibility to deal with uncontrollable changes at the site (e.g., heavy rain storms, tornadoes, etc.). Most corrective measures technologies, with the exception of removal or destruction, deteriorate with time. Often, deterioration can be slowed through proper system operation and maintenance (O&M), but the technology eventually may require replacement.

Each corrective measures alternative was evaluated in terms of the projected useful life of the overall alternative and its component technologies. Useful life is defined as the length of time the level of effectiveness can be maintained. In addition, each alternative was assessed for the long-term effectiveness and performance it affords, along with the degree of certainty that the alternative will prove successful.

5.1.5 Reduction of Toxicity, Mobility, or Volume of Wastes

As a general goal, alternatives are preferred that employ technologies that are capable of eliminating waste or substantially reducing the inherent potential for on-site waste to cause future environmental releases or other risks to human health and the environment. There may be some situations where achieving substantial reductions in toxicity, mobility, or volume may not be practical or even desirable. Estimates of how much the corrective measures action will reduce the waste toxicity, volume, and/or mobility are beneficial in applying this factor. The degree to which each alternative employs recycling or treatment that reduces toxicity, mobility, or volume was assessed, including how treatment is used to address the principle threat posed by impacted soil and groundwater.

5.1.6 Short-Term Effectiveness

Short-term effectiveness, or impact, is relevant when corrective measures will be conducted in densely populated areas or where waste characteristics are such that risks to workers or to the environment are high and special protective measures are needed. Possible factors to consider include fire, explosion, exposure to hazardous substances, and potential threats associated with

treatment, excavation, transportation, and re-disposal or containment of waste material. The short-term impact of each alternative was assessed during the evaluation.

5.1.7 Implementability and Environmental Footprint

Implementability is often a determining variable in shaping alternatives. Some technologies will require state or local approvals before construction, which may increase the time necessary to implement the alternative. In some cases, state or local restrictions or concerns may necessitate eliminating or deferring certain technologies or remedial approaches from consideration in alternative selection. The ease or difficulty of implementing each alternative was assessed by considering the following type of factors:

- Site conditions, land use, and current operations;
- The administrative activities needed to implement the corrective measures alternative (e.g., permits, rights of way, off-site or active work zone approvals) and the length of time these activities will take;
- The constructability/time for implementation and the time required for beneficial results;
- The availability of adequate off-site treatment, storage capacity, disposal services, needed technical services and materials;
- The availability of prospective technologies for each corrective measures alternative; and
- The estimated environmental footprint resulting from implementing the alternative (e.g., air emissions, energy use, waste generation, etc.).

5.1.8 Cost

The relative cost of an alternative is an appropriate consideration, especially in those situations where several different technical alternatives for remediation will offer equivalent protection of human health and the environment but may vary widely in cost. Cost estimates include costs for site preparation, construction materials, labor, sampling/analysis, waste management, disposal, permitting, health and safety measures, training, O&M and system decommissioning/site restoration. These components, as well as other applicable costs, were used to build a cost estimate for each alternative undergoing detailed evaluation. Cost estimates were obtained from representative project experience and subcontractors for the remediation alternatives evaluated. Contingencies were also included for each remedy. Present worth costs (capital plus O&M) were estimated to +50/-30 percent range. Cost estimates for evaluated alternatives are included in **Appendix C** for soil alternatives and **Appendix E** for groundwater remedial alternatives.

5.1.9 Federal, State and Community Acceptance

Evaluation of selected corrective measures must consider federal (USEPA), state (RIDEM), and community acceptance. As BASF has entered into a consent order with USEPA, this performance standard will evaluate each alternative with respect to implementation in accordance with USEPA consent order requirements and any other requirements or input received from USEPA pertaining to remediation at the Site.

Each alternative will also be evaluated with respect to potential impacts to the surrounding community (residences, local businesses, etc.). A preferred alternative will be selected. A Statement of Basis that describes the remedy will be issued by EPA, and a public comment period will commence, during which time, questions, comments or concerns may be submitted for response.

5.2 Corrective Measure Detailed Analysis Results

Given the discussion in Section 4, there are three remedial measures where alternative evaluation is required: FPA Soil, FPA groundwater and FWWTP soil. At the OWLA, the observed urban impacts will be addressed through removal and/or capping and the use of an ELUR to guide future use of this area. For the Pawtuxet River sediments, because the IRM is functioning as intended, a monitoring plan is the presumptive remedy.

5.2.1 FPA Soil

Details and descriptions of each of the six retained technologies are included in **Table 9**. The detailed analysis of the retained soil corrective measure alternatives is provided in **Table 10**. Each alternative was ranked on a scale of 1 to 6 (1 being the best) in **Table 10** with respect to the nine performance standards described above. The results of the analysis indicate that remediation to the strictest remedial standard is the most favorable outcome; however, based on cost, expected future use and implementability (recall that extensive subsurface concrete foundation structures remain in place which will encumber excavation activity), the high occupancy re-use option consisting of removal of soils with greater than 10 ppm of PCBs was chosen as the most appropriate remedy for the Site. A detailed description of the selected corrective measures and evaluation is provided in **Section 6.1**.

5.2.2 FPA Groundwater

Details and descriptions of each of the seven retained technologies are included in **Table 11**. The detailed analysis of the retained groundwater corrective measure alternatives is provided in **Table 12**. Each alternative was ranked on a scale of 1 to 7 (1 being the best) with respect to the nine performance standards described above. When assessing the best remedial alternative, one must consider the key physical attributes of the Site and the nature and extent of impact, summarized below:

1. The recalcitrant groundwater impact zone that is the focus of the remedial action considered here is associated with contaminant releases that occurred more than 40 years ago. In addition, for 12 years a groundwater capture system was operated as an IRM to address this impact by controlling groundwater discharge to river sediments and surface water (the identified receptor pathway). A second remedial system was installed and operated as an IRM to remove mass that was released from a toluene pipeline break by using soil vapor extraction (SVE) in the FPA. While some residual source is still present in upland portions of the FPA, in downgradient areas these conditions combine to result in the delineated recalcitrant mass occurring primarily as adsorbed and dissolved phase adjacent to and within the low conductivity aquifer material (silt). This mass is slowly back diffusing into the more permeable units to create the groundwater plume that is observed to be approaching the river today. Some mass that was identified in shallow areas in 2014 will be removed and disposed off-site. A remedial action that attempts to address this entrained mass through amendment emplacement will need to be applied on a fine spatial scale owing to the low conductivity material characterizing the aquifer.
2. The impact area is below and around former building foundations and footings and pilings that remain in place. These extensive concrete structures will significantly limit the ability to apply necessary amendments at the appropriate scale in terms of required spatial distribution and volume acceptance for a plume-wide approach.
3. The proposed soil remedy includes the installation of a high occupancy cap with an ELUR requiring cap maintenance and limited Site use, and the groundwater resource is classified as

GB, not for potable use. Thus, it is evident that the only complete current or future exposure pathway for this groundwater impact is groundwater discharge to river sediments and surface water. The 1995 IRM relied on groundwater containment at the bulkhead to eliminate this pathway, and a performance monitoring plan was implemented to verify that the pathway was incomplete based on MPS defined for the 5 Site VOCs.

4. One must consider the suite of compounds that a biologically-based remedial action must address. These include the five VOC COCs commonly used in the production process, identified in 1995 and assigned MPS, namely: 1,2-dichlorobenzene, chlorobenzene, 2-chlorotoluene, toluene, and total xylenes. In addition to the COCs listed above, there is a sub-area where other VOCs are uniquely identified as exceeding the RIDEM GB criteria. These include: tetrachloroethene, vinyl chloride and benzene. These compounds are not detected in on-Site soil at elevated concentrations and not likely source material based on past operational activity. Nevertheless, these compounds are generally co-located with one or more site-related COCs in excess of an MPS, and, will thus be addressed through remedial action.

Given these target compounds, the issues for a biologically-based alternative are (1) choice of aerobic, anaerobic, or both, and (2) amendment choice and delivery method. During the CMS, effort was put into a study to determine if aerobic or anaerobic mechanisms are optimal in this system and aerobic was determined to be the most effective for the suite of compounds (**Appendix F**). However, in the field there are the following challenges:

- a. Amendment delivery – as stated above most of the residual source mass is entrained in low conductivity material, and the presence of significant subsurface structures will limit amendment delivery within the treatment volume.
- b. The current conditions are anaerobic which puts attritional onus on oxygen delivery to support an aerobic process.
- c. While aerobic and anaerobic modes of degradation are apparent, there is a likelihood that the degradation of chlorinated benzenes by either mechanism could be incomplete.

There is no such ambiguity with the use of ISCO in general and ozone sparging in particular. The benefits of ozone sparging include the fact that it is among the most powerful oxidants with a very high negative Gibbs Free Energy that can degrade all the Site COCs, and if applied continuously, one can avoid the pitfalls inherent in the use of liquids and common rebound effects. Also an ozone sparge curtain has advantages not the least of which is that dissolved-phase gas can permeate low conductivity aquifer soils more effectively than can liquids. A byproduct of an ozone approach is oxygen, and it will act to stimulate aerobic biodegradation.

5. Source material discovered as part of the PCB characterization and follow-up PDI (see Section 2.5.1), can be addressed in part during the PCB-impacted soil removal (over-dig), and in part by applying an oxidant in the excavation hole near the water table to address shallow residual source material before regrading occurs. The proposed oxidant is activated sodium persulfate and is well known to completely degrade the five MPS compounds.
6. Natural attenuation of the Site VOC is apparent from the data collected during the SRI (AECOM Draft, 2014; Final 2016). Across the sampled wells, reducing conditions and degradation products (an indication of biotic degradation/activity) are apparent, as evidenced by the low dissolved oxygen and nitrate concentrations, and the presence of methane. Bacterial counts in the groundwater are high relative to unimpacted aquifers. This would

indicate that the presence of chlorobenzenes and other aromatics has stimulated the microbial population in the subsurface.

Thus, given the concepts that the purpose for the remedial action for groundwater is to protect the river sediment and water quality, that the contaminant dissolution processes are slow, that residual source material associated with SWMU11 will be addressed as part of the PCB remedy (excavation and ISCO), and that natural anaerobic degradation processes persist in the upland aquifer, the installation of an ozone sparge curtain reactive barrier between the impact zone and the river will effectively protect the river while providing support to the naturally occurring degradation processes (provide an oxygen source to support aerobic biodegradation downgradient of the sparge curtain).

This alternative is thus promulgated by this revised conceptual site model where:

1. Residual source mass was discovered in September 2014 in areas adjacent to where the former SVE system (SWMU 11) operated. This material will be removed as part of the broader groundwater remedy;
2. The remedy relies on existing natural degradation processes to address residual dissolved-phase mass in upland aquifer materials;
3. It replaces the former IRM hydraulic containment system with an ozone sparge curtain reactive barrier placed between the upland and the river to meet the objective to treat the shallow and deep portions of the aquifer and protect the river receptor; and
4. It employs the ELUR that is necessary to implement the soil remedy to eliminate direct contact considerations and provide for long-term operation, maintenance and monitoring access.

The results of the analysis indicate that ISCO and in situ aerobic biodegradation ranked best among the retained alternatives. A detailed description of the selected corrective measures and evaluation is provided in **Section 6.2**.

5.2.3 FWWTA Soil

No further action is warranted and carried forth as the remedy for the FWWTA based on development constraints requiring RIDEM approval for future development, the commercial zoning, and the conclusion of no significant risks based on a conservative unrestricted use scenario. An ELUR was carried forth in the CMS Workplan (AECOM 2014), however, the property was sold in 2004 and thus future uses can no longer be dictated by BASF. A detailed description of the selected corrective measure and evaluation is provided in **Section 6.3**.

6.0 Evaluation of a Selected Corrective Measure Alternative

6.1 FPA Soil Selected Remedy

The selected corrective measure to remediate soils is as follows:

1. Excavation and disposal of soils impacted with PCBs greater than 10 ppm at an appropriate, regulated disposal facility.
2. Limited on-site reuse/consolidation of soils with PCB content greater than 1 ppm.
3. Installation of a regulatory-conforming high-occupancy cover over soils with PCB content greater than 1 ppm and SVOC content greater than the RIDEM IC-DEC. The cover will be constructed and contoured to support a diverse native upland habitat.
4. The septic tank located east of Building 14 will be closed and/or removed during implementation of this remedy.
5. The imposition of an ELUR on the FPA, to be approved by the RIDEM, requiring, at a minimum, open space reuse only and long-term cap maintenance and monitoring.

Figure 18A and Figure 18B show two conceptual scenarios of the proposed excavation and extent of the high-occupancy cover, and Inset Figure 1 provides a conceptual regrading and native habitat enhancement plan associated with the FPA high occupancy cover remedy.



Inset Figure 1 – Conceptual regrading and native habitat enhancement plan associated with the FPA high-occupancy cover remedy and open space/parkland reuse.

Complete removal of the impacted soils is not feasible because of the fact that they are in large part located within and around former building foundations, footings, and pilings. These extensive concrete structures will limit the ability to fully remediate the area to avoid the need for a cap. However, while a cap is needed, this remedial action will allow for a high-occupancy reuse which will allow the entire FPA to be repurposed as open space/parkland, thus providing socio-economic value.

Costs and assumptions associated with implementation of the proposed remedy are presented in **Appendix C**. This represents one such scenario for this chosen option. PDI and/or post-excavation sampling may change estimated volumes and areas proposed for excavation and on-site reuse/consolidation, but the intended future use scenario will be retained as described above. The cost of the actual remedy could be different than that presented in Appendix C and will be based on the final design.

6.1.1 Remedial Approach

Excavation of PCB-impacted soils will occur in multiple phases, which may be sequential or overlap during implementation. All work will be performed following both EPA (TSCA) and RIDEM regulations. The phases are outlined below:

- **Phase I** - Excavation, verification sampling and offsite disposal of all TSCA-classified soil (i.e., soil impacted with greater than 50 ppm of PCBs). See Figure 18A and Figure 18B for two scenarios showing the target areas. As the targeted volumes are removed, a TSCA-conforming verification sampling plan will be implemented to ensure that the 50 ppm threshold has been achieved. Before excavation, disposal will be coordinated with transport contractors and disposal facilities equipped to accept the estimated volume of TSCA waste [currently 1,170 cubic yards (CY)].
- **Phase II** - Excavation, verification sampling and offsite disposal of all soil impacted with greater than 10 ppm of PCBs (i.e., the EPA requirement to allow for a high-occupancy reuse scenario). See Figure 18A and Figure 18B for the conceptual target areas. As the targeted volumes are removed, a TSCA-conforming verification sampling plan will be implemented to ensure that the 10 ppm threshold has been achieved. Before excavation, disposal will be coordinated with transport contractors and disposal facilities equipped to accept the estimated volume of non-hazardous waste containing PCBs less than 50 ppm [currently 5,100 CY].
- **Phase III** – Cover (cap) remaining soils with concentrations greater than 1 ppm with two feet of clean soil to meet RIDEM direct exposure requirements. Where soils are consolidated, employ a verification sampling plan to ensure uncapped areas conform to the threshold. At this point in the project, excavated materials will contain less than 10 ppm PCBs, which are suitable for on-site reuse under this corrective action. On-site reuse will consist of backfilling open excavations within the area to be capped to consolidate the material. Excavation areas not to be capped will not be backfilled, but will be graded to eliminate sharp changes in elevation. Within the flood hazard area, the grading plan will conform to the no-net-increase-in-fill requirement. The final cap will be constructed with clean soils containing less than 1 ppm of PCBs. Approximately 1,520 CY of clean material will be required to construct a cap two feet thick, which covers an area of approximately 39,000 SF, over the area containing the consolidated soils. The final location and quantities of the cap will be established in the Remedial Design process with the goal that all soils containing PCBs >1 ppm remaining on-Site will be capped with 2 ft of clean material. The cap will be completed and vegetated to support a diverse upland habitat.

- **Phase IV** – Impose an Environmental Land Use Restriction (ELUR) on the entire FPA, to be approved by the RIDEM, requiring, at a minimum, open space reuse only and long-term cap maintenance and monitoring.

As discussed in Section 3.1.1, caps used as remedial measures under TSCA 40 CFR 761.61(a)(7) are required to meet permeability, sieve, liquid limit and plasticity requirements. Variation from these requirements will require approval from EPA. In areas where PCBs will remain on-site at concentrations between 1 and 10 ppm, the RIDEM remediation regulations require that contact with such soil be eliminated by rendering it inaccessible beneath 2 ft of clean soil with no permeability requirement as 10 ppm meets the RIDEM GB leachability requirement. A clean soil cap of 2 ft also meets the minimum thickness requirements (10 inches) required by TSCA 40 CFR 761.61(a)(7). This RIDEM-based measure to render the soil inaccessible is an effective means of compliance with the DEC when the soil cap is maintained through implementation of an ELUR that details the configuration of the inaccessible soil area and requires that the cover be maintained. Therefore, a RIDEM cap is considered a feasible alternative to that required under TSCA 40 CFR 761.61(a)(7).

Cap materials will consist of at least 2 feet of clean materials (e.g. sand and top soil) overlying indicator materials (e.g. geotextile liner and orange fencing material) to delineate clean versus impacted soils as a warning of inadvertent disturbing of the cap.

6.1.2 Comparison of Selected Alternative to Performance Standards

This section provides an evaluation of the selected corrective measure with respect to RCRA performance standards as described in **Section 5.0**. The selected corrective measure consists of excavating soils impacted with PCBs to a 10 ppm threshold, capping soils with PCB concentrations greater than 1 ppm, but less than 10 ppm. Vadose zone soil containing elevated levels of VOCs, as well as soil near the on-Site buildings exceeding the RI DEM I/C DEC will also be removed (see discussion in Section 5.2.2). This corrective action is consistent with anticipated future use.

Protection of Human Health and the Environment

The selected alternative is protective of human health and the environment. Excavation/disposal/capping of soils to be consistent with RI DEM I/C DEC is considered appropriate for anticipated future uses as I/C property.

Attain Media Clean-up Standards

The selected alternative will achieve site-specific CAOs for soil. Excavation and disposal, with capping, is one of the most conservative and successful means to obtain clean-up goals.

Control Sources of Releases

Elevated PCB impacts will be excavated and appropriately disposed, effectively eliminating the potential for residual PCB impacts to act as a continuing source.

Long-term Effectiveness

Excavation and disposal is effective long term, and caps will be monitored to ensure there is no erosion or other means of destruction is present.

Reduction of Toxicity, Mobility and Volume of Wastes

The selected alternative will reduce the toxicity, mobility and volume of wastes.

Short-term Effectiveness

The excavation/capping plan can be implemented with acceptance of the remedial alternative. Once the remedy has been accepted, design and permitting, and procurement of an excavation subcontractor can be implemented within 6-12 months. The short-term impacts on the community will be limited by minimizing the amount of soil transported for off-site disposal.

Implementability and Environmental Footprint

Operations have ceased at the Site, thus, there are currently no existing conditions at the Site that would prevent or make difficult any of the above activities. Therefore, this alternative is considered implementable.

The environmental footprint associated with implementing this remedy is considered as having less impact than the option for unrestricted use based on reduced volumes of soil requiring handling, disposal, and subsequent backfill.

Working in and around building foundations will limit the ability to remediate to a goal of 1 ppm, thus requiring at a minimum the imposition of an ELUR and likely the use of a cap in places. These facts make the 10 ppm cleanup goal more implementable.

Cost

The cost of this remedial strategy was more expensive than a low-occupancy scenario (soils greater than 50 ppm were remediated, all others capped), but less expensive than the strictest remedial standard option (remove all >1 ppm). The cost-benefit relationship balances the total remedial costs with likely future use, and the ability of the performing party to transfer the property in the future.

Federal, State and Community Acceptance

In general, excavating PCB-impacted soils and capping residual impacts to a 10 ppm threshold would be accepted by various federal, state, and local stake holders. The corrective measure adequately addresses risk to human health and the environment for likely future use scenarios without limiting occupancy for the IC use category.

Permits from the City of Cranston Planning and Zoning and RI DEM Wetlands department would be needed to excavate within the 100-yr flood plain and the wetland buffer zone within the Pawtuxet River areas.

This alternative will incorporate comments following the public notice comment period.

6.2 FPA Groundwater Selected Remedy

Groundwater will be addressed through a three step plan. First, residual VOC source material located in the upland near SWMU11 will be in part excavated from the vadose zone as part of the PCB remedy and disposed of offsite and in part destroyed in-situ with a chemical oxidant (base or peroxide activated sodium persulfate) by physically mixing the oxidant into the vadose and saturated zones before re-grading the area to support the soil cover. Second, for the groundwater plume that has migrated to the vicinity of the river bulkhead, an in-situ reactive barrier will be installed parallel to the

river bulkhead and normal to the groundwater flow direction to destroy VOC mass in-situ before it migrates off-site and discharges to the Pawtuxet River. The proposed oxidant is ozone, and it will be applied to the aquifer in a continuous fashion using a line of wells that overlap in their volume of influence (a sparge application). The remedy will be run on the order of years until such time as upgradient and downgradient monitoring show that the media protection standards have been met. The ozone will destroy all contamination in which it comes in contact, and it will also contribute oxygen to the groundwater to support aerobic biological degradation. The remedy design including the treatment volume, number and orientation of injection wells, and monitoring requirements will be determined from a pilot testing program. Third, for dissolved upland VOC mass, monitored natural attenuation (MNA) will be used to show mass attenuation over time. These remedial measures in concert are appropriate given site-specific conditions including extensive in place building foundations which limits access to aquifer materials and low conductivity heterogeneous aquifer material coupled with the age of the impacts (greater than 40 years) which limits the mobility of the dissolved-phase mass. Finally, this remedy is consistent with that proposed for the upland soils and the imposition of an ELUR that will limit future land use to open-space and require long-term operation and maintenance.

The conceptual remedial area is illustrated in **Figure 16** and constitutes a remedial measure that is protective of the river, removes on-going sources, and monitors for natural attenuation between the source and treatment barrier located adjacent to the river.

Details on costs and assumptions for implementation for the in situ remediation alternatives are included in **Appendix E**. Amendment quantities and injection rates/durations were estimated. The potential technologies to be used are described below.

6.2.1 In-Situ Chemical Oxidation – Source Zone

ISCO is the selected remedial alternative to treat COCs in the shallow groundwater interval of the residual source zone in upland portions of the FPA associated with SWMU11 (see **Figure 16** for location). The target COCs for treatment are 1,2-dichlorobenzene, chlorobenzene, 2-chlorotoluene, toluene, and xylenes. Base or peroxide activated sodium persulfate are proposed oxidants. Persulfate has been effective at oxidizing the targeted COCs (e.g. Sedlak and Andren, 1991, Huang, *et al.*, 2005, ITRC, 2005, and Luo, 2014).

6.2.1.1 Description of Technology

ISCO involves the injection of an oxidizing substrate to the subsurface with the objective of promoting oxidation of target compounds to benign end products. Activated sodium persulfate is proposed for the remedial approach. Sodium persulfate is a strong chemical oxidant that can persist for weeks to months. This attribute will allow some portion of the persulfate to be transported under induced and natural gradients prior to fully reacting, allowing the oxidant to get better distribution in the subsurface and treat more contaminant mass downgradient from the residual source area. For remediation applications, sodium persulfate needs to be activated (catalyzed) in order to form powerful free radicals, including sulfate radicals ($\bullet\text{SO}_4^-$), which are more powerful oxidants than persulfate. Activating agents include elevated temperatures, ferrous iron (Fe(II)), elevated pH (base), and peroxide.

6.2.1.2 Remedial Approach

The remedial approach in the residual source area is to first excavate VOC-impacted soil in the vadose zone and dispose of it at an appropriate disposal facility. This excavation will occur at the

same time as the remediation of the PCB-impacted soil. Based on the PDI data, the excavation is initially planned to encompass an area of 400 to 750 square feet, and it will extend to the water table. Excavation will be monitored with visual cues (i.e. staining) and photo-ionization detector (PID) as screening tools, and if necessary it will be expanded in area initially based on screening and subsequently based on confirmatory sidewall sampling to compare concentrations to RIDEM GB Leachability Criteria.

Once vadose zone mass has been removed, the oxidant will be placed in the excavation and mixed into the top three to four feet of the saturated soil within the shallow aquifer using an excavator bucket of specialized excavator attachment. The oxidant dosing will be based on the total oxidant demand of the soil and a factor of safety. The volume of oxidant solution (diluted with water) will be equivalent to at least approximately 3 pore volumes of the saturated thickness of soil to allow for the oxidant to disperse away from the excavation. The excavation will then be backfilled.

Approximate excavation and mixing locations and volumes were evaluated in this CMS and are included in **Appendix D**.

6.2.2 In Situ Chemical Oxidation – Pawtuxet River Barrier

ISCO is the primary remedial technology selected for a treatment barrier located adjacent to/upgradient of the Pawtuxet River. The treatment barrier will be installed into the upland aquifer along a transect parallel to the bulkhead along the Pawtuxet River destroying contaminants in situ. The purpose of the barrier is to break the transport pathway and treat impacted groundwater discharging to surface water. This approach is protective of the sensitive receptor. This remedy will employ an ozone sparge curtain to fully treat the COCs located in the southern portion of the FPA. Continuous operation of the sparge curtain will intercept Site COCs in permeable transport pathways.

6.2.2.1 Description of the Technology

This alternative involves installing an ozone sparge barrier using a series of closely spaced wells through which ozone is forced into the aquifer under pressure between the upland aquifer and the Pawtuxet River to destroy the resident COCs as they migrate.

Ozonation is a very common potable water and wastewater treatment technology. Over the past 25 years, more and more case study literature has been published that supports the concept of also using ozonation for treating complex organic pollutants, including the VOCs detected at the Site (<http://www.kerfoottech.com/> and Siegrist et al., 2011).

Ozone is one of the strongest oxidants available for in-situ chemical oxidation; therefore, it should be effective at remediating the VOCs. The barrier system will remediate the COCs directly upgradient of the bulkhead in efforts to meet the remedial action objective to protect river sediments and surface water from discharging site-related contamination.

A monitoring plan will be implemented to determine the effectiveness of the barrier by providing a measure of the mass flux of contaminants across the barrier (a function of barrier thickness and continuity), where dedicated wells are installed upgradient, within and downgradient of the barrier along flow lines, and they are monitored for COCs, as well as, geochemical parameters (e.g. dissolved oxygen, specific conductivity, pH, turbidity). The barrier will be operated until such time as mass transport from the upland no longer affects water quality above the MPS or GB criteria at the downgradient monitoring point. In addition to barrier functionality, these data are used to provide

design information regarding barrier dosing requirements and natural attenuation of residual dissolved mass located up-gradient of the barrier.

6.2.2.2 Remedial Approach

The treatment barrier will be designed to remediate the shallow and deep zones that exceed the applicable MPS or GB standard for those target compounds with no MPS. For the purposes of this CMS, one such conceptual approach is carried forth to demonstrate a potential treatment geometry (**Appendix D**). This is based on the high resolution hydrogeological data collected during the site investigation. The estimated area of the treatment barrier is 200 ft long by 40 ft deep [between 6 and 46 feet below ground surface (bgs)]. Typically, vertical injection wells are used and they are spaced and screened to target the ozone where required. The estimated number of ozone injection wells in the shallow zone is five (5), and in the deep zone is thirteen (13). This is based on an estimated zone of influence of 15 feet.

Performance monitoring will be used to determine the barrier's effectiveness. Overall performance will be evaluated based on concentration trends and achieving MPS or RIDEM GB groundwater criteria for the identified COCs. It is worth reiterating that a byproduct of ozone degradation is dissolved oxygen, which has been shown to stimulate bacterial populations found at the Site (**Appendix F**), which enhances natural attenuation.

The infrastructure required for the duration of the remedy will include the ozone source and the equipment and power needed to deliver it into the aquifer (housed in a trailer located near the application area), and a series of injection wells (with trenched piping) and performance monitoring wells.

A pilot test will be implemented to show proof of concept and establish design parameters to support the full scale application, specifically the spacing and orientation of injection wells and the need for surface area enhancement in the subsurface should low permeability aquifer materials inhibit distribution. Performance monitoring will occur in upland locations upgradient and downgradient of the piloted barrier. Performance sampling parameters will be outlined in a pilot test work plan, but they typically include sampling for contaminants, groundwater elevations, temperature, flow rates of the injected oxidant, wellhead pressure, geochemistry (e.g. dissolved oxygen, specific conductivity, pH, turbidity), total dissolved solids and/or select metals, and total organic carbon. The frequency and duration of monitoring will be established in a pilot test work plan, but the plan will consider appropriate timeframes to establish effective zone of influence and effectiveness of the oxidant to treat the COCs. Results from the pilot test will be used to develop the full-scale design of the barrier.

6.2.3 Aerobic Biodegradation – Pawtuxet River Barrier

Aerobic biodegradation is a secondary option for implementation as the selected remedial alternative to treat COCs in more permeable portions of the aquifer located near the bulkhead. The target COCs for treatment are 1,2-dichlorobenzene, chlorobenzene, 2-chlorotoluene, toluene, and xylenes. In addition, aerobic biodegradation has been shown to degrade chlorinated ethenes in the laboratory bench scale test, but should be confirmed with field data from a pilot test prior to full-scale implementation, if implemented.

6.2.3.1 Description of Technology

Aerobic biodegradation uses indigenous or introduced aerobes to biodegrade COCs. Frequently, impacted aquifers are oxygen-limited, thus implementation of this technology often involves

reintroducing oxygen to the aquifer to accelerate naturally-occurring in situ bioremediation. To this end, commercially available products are available to distribute high concentrations of dissolved oxygen into the aquifer via oxygen diffusers (e.g. in situ Submerged Oxygen Curtain [iSOC]) installed into screened wells within the treatment interval. Oxygen is passively distributed to the diffusers in the wells using regulated tank pressure. Super-saturated dissolved oxygen-infused groundwater is then transported under natural gradients, which then becomes available to aerobic bacteria. Bench scale tests have shown this aerobic bioremediation to be effective for Site COCs using geologic materials collected at the Site.

6.2.3.2 Remedial Approach

A conceptual approach is described for implementation of aerobic biodegradation as a treatment barrier which includes installing wells along the length of a transect located adjacent to the Pawtuxet River in a barrier geometry. Oxygen diffusers will be installed in the wells, which will be screened from approximately 16-26 ft bgs, or deeper if warranted. The screened interval will intersect permeable portions of the aquifer that act as transport pathways from upland portions of the FPA to the Pawtuxet River. Dissolved oxygen (DO) concentrations approach 30-50 mg/l within the well. DO-saturated groundwater is then transported from the wells under natural gradients and dispersed into the aquifer stimulating the native aerobic microbial populations, which degrade COCs. Because diffusion is the main mechanism for distribution of DO-saturated groundwater, the barrier geometry differs from the ozone sparge technology described above. Where the ozone sparge must contend with application of a gas which may be buoyant and placed below the treatment interval, the oxygen diffusers may be screened across the intervals with the highest mass flux, hence a slightly different treatment geometry, but with similar outcomes.

Aerobic biodegradation has documented success in treating chlorobenzene, 1,2-dichlorobenzene, 2-chlorotoluene, benzene, toluene, xylenes, and the lower order chlorinated ethenes (e.g. TCE, VC). PCE has been shown to be degraded by co-metabolically produced enzymes from bacteria that consume other carbon sources for food in the subsurface. The assumptions used for the remedial approach include using dissolved oxygen in the vicinity of the Pawtuxet River. An approximate barrier location was evaluated in this CMS and is included in **Appendix D**.

6.2.4 Monitored Natural Attenuation

Monitored Natural Attenuation (MNA) is a technology that relies upon the natural reduction of contaminant concentrations in groundwater resulting from the combined effect of dispersion, diffusion, volatilization, sorption, abiotic degradation, and biodegradation. MNA is incorporated as a component of the remedial approach to document restoration of the upland aquifer over time. .

6.2.4.1 Description of Technology

MNA quantifies natural attenuation mechanisms that are active at the Site. These include: dispersion, diffusion, volatilization, adsorption, abiotic degradation and biotic degradation. Dispersion and diffusion are transport mechanisms that reduce COC mass flux across a unit area and COC concentration at monitoring locations, but not the total mass in the aquifer (i.e., a dilution phenomenon). The heterogeneous and low conductivity nature of the aquifer materials will promote dispersion and diffusive transport into fine-grain materials, where discharge will be reduced and where biotic and abiotic degradation has an opportunity to reduce the mass in place. Volatilization is a function of the contaminant's volatility (defined by its Henry's law constant) and site specific considerations, including proximity to the COC impact to the water table and the conductivity of the aquifer materials. Sorption to aquifer materials is a function of the aquifer's organic carbon content

and the contaminant's affinity for that carbon (defined by its K_{OC}). Degradation of the contaminants through abiotic (chemical reactions with aquifer minerals) and/or biotic (chemical reactions with bacteria resident in the aquifer matrix) means is an attenuation mechanism, where the contaminant mass is destroyed in-situ through these natural processes.

6.2.4.2 Remedial Approach

MNA will be implemented by monitoring the spatial and temporal trends in concentration at locations along mid-plume locations and the downgradient side of the reactive barrier to verify that there is a restorative trend in general and to show that COC concentrations leaving the Site are below respective MPS and GB criteria during and after operation of the reactive barrier. Based on an evaluation of MNA parameters at the Site, MNA will complement the active ISCO/aerobic treatment.

As part of the remedial investigation, MNA parameters were collected in the vicinity of the reactive barrier, and the following conclusions are presented:

- Across the sampled wells, reducing conditions (an indication of biotic degradation) are apparent, as evidenced by the low dissolved oxygen and non-detect nitrate concentrations, and the presence of methane. In this situation, the strongest evidence of reducing conditions is the presence of methane.
- Bacterial counts in the groundwater are high relative to unimpacted aquifers. This would indicate that the presence of chlorobenzenes and other aromatics has stimulated the microbial population in the subsurface.
- After oxygen depletion, denitrification takes place. During this time, all aromatic VOCs measured (toluene, total xylenes, chlorobenzene, 1,2-dichlorobenzene, benzene, 2-chlorotoluene) were likely actively mineralized. Once oxygen and nitrate are consumed, mineralization of the COCs decreases.
- The enzymes oxygenases (both mono- and di-) are present, and while they require oxygen to function, they are instrumental in mineralizing the benzene-related COCs.

In summary, based on the available data, an active microbial community is present at the Site. Presently, it is electron acceptor-limited and therefore unable to fully degrade the contaminants. Under the current conditions, the community is actively dechlorinating higher chlorinated aromatics. With the reintroduction of an electron acceptor (e.g. O_2), the microbial population would likely resume rapid degradation of chlorobenzene, 1,2-dichlorobenzene, benzene and lower chlorinated aromatics.

A monitoring program will be implemented to analyze trends of COCs and pertinent MNA parameters upgradient and downgradient of the reactive barrier. The performance monitoring parameters and frequency will be outlined in a Remedial Action Work Plan, but they typically include sampling for the COCs, geochemistry (e.g. dissolved oxygen, specific conductivity, pH, turbidity), total organic carbon, terminal electron acceptors (e.g. nitrate, sulfate, iron), and occasional bacterial census to evaluate whether bacterial populations at the Site continue to be present in sufficient numbers to effectively treat COCs. Performance monitoring evaluations will be conducted in concert with the ISCO barrier performance evaluations to determine whether natural attenuation is sufficient to address groundwater impacts in concert with or independently of the ISCO barrier approach. It is anticipated that over time MNA will become the sole groundwater remedy based on the record of spatial and temporal trends in COC concentration.

It is worth noting that injected reagents will likely work cooperatively with the available microbial populations. In addition to potentially stimulating the aerobic biological pathway, generation of heat through the ISCO process should stimulate the volatilization of COCs in the shallow aquifer. ISCO would also introduce oxygen to the aquifer which would enhance naturally occurring degradation processes.

6.2.5 Comparison of Selected Alternative to Performance Standards

This section provides an evaluation of the selected corrective measure with respect to RCRA performance standards as described in **Section 5.0**. The selected corrective measure consists of three parts (see **Figure 16** for remedy illustration):

- Focused in situ remediation using an ozone sparge curtain located between the upland groundwater impacts and the river in order to eliminate the exposure pathway. This technology will be proven in the field through the implementation of a pilot test. If this technology is shown to be ineffective, then another oxidant will be identified or aerobic biodegradation will be considered;
- Source zone excavation of VOC-impacted soils to the groundwater table and subsequent mixing of oxidant into the shallow aquifer materials prior to backfilling; and
- MNA to document aquifer restoration over time.

This remedy is consistent with the following site-specific attributes discussed in Section 5.2.2.

- The remedy addresses residual source material associated with both SWMU11 and building 16 releases, the former through excavation and ISCO (activated sodium persulfate), and the latter through ISCO (ozone).
- The remedy addresses the only completed exposure pathway for groundwater: discharge of impacted groundwater to river sediments by maintaining a treatment barrier between the upland aquifer and the river. Human health exposures are nullified through the use of a soil cap and an ELUR associated with the soil remedy and the GB groundwater designation.
- MNA is supported throughout the upland plume based on attenuation characterization data (bacterial counts and geochemistry). Ozone itself is a destructive technology, but also decomposes to oxygen, thus the ozone will provide an oxygen source to support aerobic biodegradation downstream of the reactive barrier.
- The remedy takes into account the fact that there are significant impediments to aquifer access most notably the FPA ELUR required to maintain the cap associated with the soil remedy.

This alternative is thus promulgated by this revised conceptual site model where:

- The remedy relies on existing natural degradation processes to address residual dissolved-phase mass in upland aquifer materials;
- It replaces the former IRM hydraulic containment system with an ozone sparge curtain reactive barrier placed between the upland and the river to meet the objective to treat the shallow and deep portions of the aquifer and protect the river receptor; and
- It treats residual source materials through excavation and oxidation. Treatment of the source will facilitate MNA in the main portions of the plume.

- It employs an ELUR that is necessary to implement the soil remedy to eliminate direct contact considerations and provide for long-term operation, maintenance and monitoring access.

6.2.6 Evaluation Criteria

6.2.6.1 Overall Protection of Human Health and the Environment

This remedy provides protection of human health and the environment:

- The ozone barrier breaks the GW/SW interaction pathway, thus protecting surface water and sediment quality in the river from impacts by Site COCs.
- Ozonation results in complete destruction of COCs (no treatment residual, byproducts, or contaminant – any excess ozone required to drive the degradation reactions to completion degrades into oxygen).
- In concert with the soil remedy (i.e. ELUR and soil cap), direct contact with residual dissolved mass is eliminated.
- The ELUR and remedy infrastructure: ozone generator, injection and monitoring wells, injection equipment, and soil cap, effectively and permanently address human and environmental risks in the short-term and long-term.
- The former P&T has shown that natural attenuation is effective to address residual dissolved mass in the long-term.
- In contrast to other oxidants that leave excess oxidant such as manganese or sulfate (from permanganate or persulfate respectively) in the treated groundwater, ozone sparging would only add dissolved oxygen. Ozone is short-lived in the environment. If any residual ozone remained in the groundwater that discharges to the river, it would be degraded to oxygen immediately upon contact with organics in the river water or sediment.
- Reducing or eliminating residual source materials in the upland portion of the FPA will facilitate MNA in the mid-plume areas.

6.2.6.2 Attain Media Cleanup Standards

This remedy will attain media cleanup standards:

- Ozone provides complete destruction of COCs (no byproducts, treatment residuals); as a result, MPS and GB standards for groundwater would be attained downgradient of the ozone sparging barrier.
- The former pump and treatment system has shown that hydraulic control is effective to meet the MPS and in so doing protect the river receptor.
- Natural attenuation upgradient of the ozone sparge barrier will address residual dissolved mass as it diffuses out of low conductivity saturated soils, rendering the mass flux negligible over time.
- Monitoring upgradient and downgradient of the barrier will be used to track and demonstrate attainment of MPS and GB standards.
- Residual source removal will facilitate attainment of the media cleanup standards by eliminating an ongoing source of impacts to groundwater.

6.2.6.3 Control the Sources of Releases

- The source of releases would be controlled by the soil remedy (soil excavation, local ISCO, ELUR and capping), coupled with the ozone sparge barrier to break the GW/SW interaction pathway, thus controlling the residual impacts to the river.
- Ozonation will result in complete destruction of COCs (no byproducts or treatment residuals).
- Long-term monitoring will ensure controls remain effective in the long-term.

6.2.6.4 Long-Term Reliability and Effectiveness

- Ozone has been shown to be an effective oxidant for the target COCs (Huling and Pivitz, 2006).
- Ozone sparge curtain has a long track record of commercial scale application (Kerfoot Technologies, 2015)
- Ozone can permeate the aquifer materials in two ways: transport as a gas phase and subsequent dissolution and transport into the water phase.
- Monitoring up-gradient and downgradient of the barrier will be used to track and demonstrate attainment of MPS for groundwater in the long-term.
- A pilot test will be used to confirm site-specific effectiveness and establish design parameters - with specific reference to radius of influence - for full-scale application.
- The permanent infrastructure (wells, piping, etc.) will support long-term effectiveness, and it can be adapted to an alternative amendment application, as the data support.
- Treating the residual source zone will enhance the long-term reliability and effectiveness.
- MNA will eventually replace the reactive barrier as aquifer restoration reduces the contaminant mass flux.

6.2.6.5 Reduction of Toxicity, Mobility, or Volume of Wastes

- By completely destroying COCs without generating any treatment residuals or byproducts, ozone sparging would completely eliminate the toxicity and mobility of the COCs of interest.
- Ongoing natural attenuation of residual mass located up-gradient of the barrier will result in the reduction, over time, in the total mass remaining and its mobility (reduced mass flux over time).
- The application will not mobilize contaminants as this is a weathered release present in adsorbed and dissolved phases only.
- In contrast to other oxidants that leave excess oxidant such as manganese or sulfate (from permanganate or persulfate respectively) in the treated groundwater, ozone sparging would only add dissolved oxygen. Ozone is short-lived in the environment. If any residual ozone remained in the groundwater that discharges to the river, it would be degraded to oxygen immediately upon contact with organics in the river water or sediment.

6.2.6.6 Short-Term Effectiveness

- This alternative would be effective in the short term because ozone, upon contact with the COCs, provides instantaneous destruction of Site COCs.

- Ozone is a powerful oxidant and appropriate health and safety precautions will be implemented to ensure it is handled and conveyed safely to the sparging wells. Because the ozone would be generated on site as needed, no special health, safety, or handling will be needed off-site. Health and safety guidelines are noted in the References Section.
- In contrast to other oxidants that could put elevated levels of manganese or sulfate (from permanganate or persulfate respectively) and impact the river, the ozone treatment would if anything only add oxygen to the river. Ozone can't persist very long and even if it reached the river it would be degraded instantly upon contact with anything organic.
- See also criteria for long-term effectiveness as they also apply to effectiveness in the short-term.
- Source zone removal would have limited impacts on adjacent businesses and residences.

6.2.6.7 Implementability and Environmental Footprint

Site conditions support implementability in the following ways:

- There are no significant surface or subsurface impediments to treating Site COCs using an ozone sparge barrier in the vicinity of the bulkhead. The barrier would be oriented perpendicular to the groundwater flow direction and at the proper depths to intercept groundwater impacted with Site COCs at levels exceeding MPS and GB standards.
- The geology is unconsolidated sands and silts which is amenable to well installation at the required depths.
- The alternative does not require invasive work to be implemented in the upland residual impact area where there are significant subsurface impediments (foundations, footings and piers) that limit the accessibility of this area at the appropriate spatial scale.
- Long-term siting of remedy infrastructure and site access is guaranteed through the imposition of an ELUR, which in part is required for the soil remedy.
- An UIC permit will be required.
- The environmental impact of an ozone treatment system from a sustainability perspective is best characterized by pointing out that competitive oxidants like permanganate and persulfate and for that matter any of the biological treatment modalities require synthesis and shipment of chemicals, sometime across long distances (India, China, Eastern Europe). Ozone is generated on-site by passing air through a simple electrical arc.
- Source zone treatment is implementable with common heavy machinery (excavation, oxidant mixing).

6.2.6.8 Cost

The estimated costs for this corrective measure strategy are presented in **Appendix E**, as Alternative 4.

Estimating Assumptions

The following general assumptions were considered in developing the cost estimate for this alternative.

- The treatment barrier will be designed to remediate the shallow and deep zones that exceed the MPS. The estimated length of the treatment barrier is 200 feet (**Appendix D**). The treatment thickness is estimated at 40 feet, between 6 and 46 feet below ground surface (bgs) (**Appendix D**). The estimated number of ozone injection wells in the shallow zone is five (5), and thirteen (13) in the deep zone. This is based on an estimated zone of influence of 15 feet. The estimated capital cost to install 18 ozone injection wells, six (6) monitoring wells in the shallow zone and six (6) monitoring wells in the deep zone, trenching and piping, procure and mobilize an ozone generator, electrical connection is \$482,000. The estimated annual O&M cost is \$154,000. This includes weekly O&M, electrical usage, system's evaluation, quarterly performance groundwater monitoring, and quarterly performance report.
- Continuous ozone sparging will occur for 5 years, while monitoring will continue for 30 y.
- The total 30 year cost is \$2.3 MM.
- Costs are based on vendor experience with ozone remediation projects
- Actual costs will be based on competitive bids from drilling, trenching and piping vendors, electrical contractor, and ozone equipment.
- The number of injection and monitoring wells and well spacing as described above. The actual configuration will be based on a field pilot test.
- Performance monitoring includes laboratory analysis for VOCs and hexavalent chromium, and field analysis for pH, oxidation-reduction potential, and dissolved oxygen.
- Contractor markup, engineering design, and construction management percentage are based on conventionally accepted values.
- Any permits beyond those normally needed for the type of project and project conditions are excluded

6.2.6.9 Federal, State and Community Acceptance

- The remedy is not technically complex: Groundwater flows through a residual groundwater impact zone on its way to the river and in so doing transports dissolved-phase COCs. A curtain of ozone is injected into the subsurface between the upland and the river to destroy resident COCs before they are transported offsite. The sparge curtain is maintained through a surface infrastructure (trailer). Groundwater samples are collected upgradient and downgradient of the curtain to monitor effectiveness of the curtain and depletion of remaining residual mass located upgradient of the curtain.
- The remedy is an in-situ technology that has a small surface footprint, which will not create a significant visual effect.
- The remedy addresses risk-based standards through the combinatory use of the barrier (groundwater treatment) and an ELUR (maintain soil cap, allow access).
- Incorporating residual source treatment in the upland portion of the FPA will enhance the effectiveness of the ozone barrier and mid-plume MNA.

6.2.7 Evaluation Comparison to Other Groundwater Alternatives

This Alternative is an ISCO remedy, and for the reasons introduced above, ISCO has advantages over aerobic bioremediation technologies. As detailed above, using the oxidant ozone is considered the most appropriate ISCO application for the site conditions and remedial action objectives. While the

ISCO remedy is more expensive than the biologically-based remedies, they are technically more robust given the site conditions, and this should reduce some uncertainty in cost, therefore rendering the ISCO remedy on par with the bioremediation with regard to cost. Further, treatment of the residual source material will enhance the effectiveness of the ozone barrier and the MNA of the mid-plume areas.

Detailed implementation, design, and performance monitoring plans will be developed in subsequent documents following implementation of the pilot test.

6.3 OWLA

To address RIDEM Regulations, BASF will remove or cover the soil with exceedances of the I/C DEC and impose an ELUR for this area to be approved by the RIDEM. The ELUR will include the following restrictions: non-residential use only, must employ a soil management plan for any invasive work conducted on the property, and must, on an annual basis, report to the RIDEM that the terms of the ELUR are being met.

6.4 Pawtuxet River Sediment

Several technologies presented in the Stabilization Report (Woodward-Clyde, 1996) have already been constructed in the Production Area. The technologies that were identified to be protective of sediment and river quality include sediment excavation, disposal, capping, and extraction wells (hydraulic control system) for hydraulic control of on-site groundwater from migrating into the river. The groundwater extraction and treatment system operated from 1996 to 2010 when long-term monitoring data showed aquifer restoration was complete except for a recalcitrant area. The recalcitrant area was the subject of extensive remedial investigation (AECOM, 2012), and it is a subject of this CMS (Section 6.2).

Given the historic remedial measures completed for sediment at the Site, a long-term periodic monitoring program will be implemented to ensure the existing sand cap remains intact and protective. Monitoring frequency is initially proposed to occur at the first five year review (2021) and after major flood events between now and that time (defined by NOAA as a Pawtuxet River stage that exceeds 13 ft MSL at the USGS gage station 01116500). Under the monitoring plan, the sand cap will be sampled for PCB content to ensure that any remaining PCBs sequestered below the cap are not permeating the cap. Cores of the cap will be collected along the center line at upstream, midstream and downstream locations (3 cores) and samples will be collected for PCB analysis from the 0" to 3" and 3" to 6" horizons (2 samples per core). If PCBs exceed 1 ppm in any sample, additional investigation will be conducted to determine the source of the detections and appropriate remedial measures necessary to ensure protectiveness, if any. A detailed monitoring and sampling plan will be developed following this outline. At the time of the 5 year review, based on the data in hand, a decision will be made as to the permanence of the remedy and future monitoring requirements.

6.5 FWWTA

The selected remedy for the FWWTA includes No Further Action. The FWWTA is zoned for commercial use and currently is used as a landscaping operation. A risk assessment completed in 1995 (Ciba) determined that there were no significant risks associated with a conservative reuse scenario of an on-site resident (despite commercial zoning). The 200 ft Riverbank Wetland prevents development and soil management without RIDEM approval.

7.0 References

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Woodward-Clyde, Sediment IRM for the Pawtuxet River, 1996.

Tables



Table 1
SWMU/AOC Descriptions - Production Area
Corrective Measures Study

BASF
Cranston, Rhode Island

Mill Street-SWMU/AOC		
Area Number	Description	Status
SWMU 2, 3, 7	Former tank farm area where rail cars were loaded. Secondary containment was present and no spills were noted. The only data available to review were from 1994. To evaluate for current soil and groundwater conditions, additional data were proposed for collection prior to Site closure.	Based on SRI, no further action is warranted.
SWMU-4	SWMU 4 was an area that contained a trash compactor where solid wastes were disposed and broken down	Based on SRI, no further action is warranted.
SWMU-8	A historic spill was noted at nearby SWMU 4 and a former Site plan notes a Solvent Recovery Area in this area, which had not been previously identified as a specific AOC or SWMU and had not been previously investigated in the RFI	Based on SRI, no further action is warranted.
SWMU-11	A documented toluene spill from a pipeline to a subsurface sump at Building #11 occurred in the early 1980s. A SVE system was operated and post-closure monitoring indicated that COCs were remediated.	Based on samples collected during PCB grid sampling, residual VOC source material is present in the shallow vadose zone soils and requires further remediation to address this potential on-going source to groundwater.
AAOI-15 Former Laboratory Building Piping	A laboratory sump was present within the laboratory building and interviews with facility personnel indicated that dyes may have been washed down laboratory sinks in the 1960s and potentially discharged at an outfall in the river	Benzo(a)pyrene and dibenzo(a,h)anthracene were elevated above the RIDEM DEC levels at SB-128 for industrial/commercial use
NAPL Area Near MW-34D	During installation of MW-34D, a separate phase liquid was tentatively (visually) identified as Dowtherm, but no confirmation sampling was completed on this material. It was reportedly present from 14-30 ft bgs, throughout a 6,400 sq ft area. The potentially impacted soil in this area is inaccessible but needed to be evaluated if it was a remaining source that impacts long-term groundwater quality. The only data available to review were from 1994	Recent groundwater results from MW-34S show a MPS exceedance for total xylenes. No NAPL was observed in the well.
Jet Sump Area	There was a boiler plant jet sump failure in the southern portion of the site and observation of possible solvent in the sump in the mid-1970s. Footings for the boiler plant were exposed and a large area beneath the building was filled in with concrete for structural support in approximately 1978 (based on interview with facility staff). This area coincides with the elevated soil concentrations denoted in the 2007 MIP investigation at MIP-1, MIP-2, MIP-5, and MIP-7 (see Figure 3-2 for 2007 MIP locations).	This area coincides with the elevated soil concentrations denoted in the 2007 MIP investigation at MIP-1, MIP-2, MIP-5, and MIP-7. This area appears to host the highest concentrations of VOCs in soil and groundwater on the Site. Primarily, the former Building 16 area has high VOC concentrations as well as the former Building 23 area to the west, Building 19 to the north and Building 22 to the northeast. VOC impacts in the former Jet Sump Area have been adequately delineated.
Buildings #10/#18 Boiler Room & Transformers	Historically, this area contained boilers and transformers.	Total PCBs were detected at a concentration of 71.8 mg/kg at SB-119 at a depth of 4-6 ft bgs, adjacent to the transformer area. This detect is below the depth that is accessible.
Building #24 Zinc Rail Car Area	Dry chemicals were loaded into rail cars at this location.	No further action for this area is warranted
Building #21 Zinc Sump	Soil samples were collected to delineate zinc surrounding the zinc sump.	Elevated PCBs identified in this location. The presence of PCBs is likely related to the former activities at Buildings 19 and 16.
Building #21 Tank Farm	Historically, this was a former tank farm that supported pharmaceutical manufacturing activities in Building #21	The former Building 21 tank farm area appears to be on the northern edge of the residual zone containing Site COCs that impact downgradient groundwater. The chlorobenzene concentration in soil was 16.4 mg/kg.
Piping Runs	The underground piping transported material from building to building on-Site. There were no documented releases from the piping, aside from the toluene release in the 1980s.	Impacted by the site-wide PCBs in soil. No other COCs are elevated along the former piping runs with the exception of SB-133 at the southern end of the former piping run where 2-chlorotoluene, toluene, and chlorobenzene were in the part per million range. Potential impacts were noted in the upland portion of the FPA where elevated COCs other than toluene were noted.
Hot Sump	A “T” junction between the hot sump and the outfall where the cofferdam was located was selected for a location to investigate. The cofferdam was related to a majority of the sediment impacts that were addressed in earlier remedial actions	No further action for this area is warranted
Soil Vapor	Potential release in and around the former office, lab and warehouse area	No unacceptable risk to indoor air.



Table 1
SWMU/AOC Descriptions - Production Area
Corrective Measures Study

BASF
Cranston, Rhode Island

Mill Street-SWMU/AOC		
Area Number	Description	Status
Septic Tank	Based on historical information, the site previously utilized one septic system for wastewater disposal prior to Ciba building a wastewater treatment plant off-Site in 1975. The associated sewage tank is located to the east of Building 14.	No soil or groundwater impacts adjacent to this area are apparent, therefore this area does not appear to represent an ongoing data gap. However, the septic tank will be properly abandoned during future Site remedial actions
UST Vault/Underground Tunnel	Former USTs and a below-ground vault located on the northeastern portion of the site were decommissioned according to BASF staff interviews, but no confirmatory sampling or closure reporting exists.	No indications of releases/ongoing releases have been observed in this location.
Loading Dock	Manufactured chemicals were shipped off-site in this loading dock area. No spills or releases were documented.	No further action for this area is warranted
Former Laboratory Buildings (#20 and #26), Warehouse (#25) and Warehouse	The northern area of the site between the laboratory and warehouse buildings, next to former sanitary sewer (vitrified clay) lines, were investigated to evaluate for potential impacts resulting from laboratory operations.	TPH and SVOCs were identified above R DEC and I/C DEC in the parcels located to the north of the site buildings. These parcels served as parking areas for the site buildings. SVOCs have been identified at elevated concentrations in the vicinity of the Site and are generally found in industrialized areas with long history of use. On the eastern side of the site buildings, benzo(a)pyrene was identified above I/C DEC in shallow soil.
AOC-13	The former Production Area where most of the manufacturing took place.	Covers all areas within former Production Area discussed above, including: Piping Runs, MW-34D Area, SWMU-11 area, Jet Sump Area, Building 21 Tank Farm



Table 2
SWMU/AOC Descriptions -
Waste Water Treatment Area
Corrective Measures Study

BASF
Cranston, Rhode Island

Waste Water Treatment Property-SWMU/AOC		
Area Number	Description	Status
SWMU-10	50,000 gallons of waste water escaped from a break in an underground pipeline in the wastewater treatment plant. The water reached the surface, flowed around an equalization tank, into a pond, and into the Pawtuxet River.	Based on risk assessment/characterization of the WWTA, no corrective action is warranted.
SWMU-12	A biological waste water treatment plant which operated from 1975 to 1986 when the plant closed. While in operation, occasional sump overflow from trickling towers occurred. These waste waters would have contained volatile and semi-volatile organic compounds. Other discharges resulted in NPDES permit exceedances for zinc, BOD, and phenols. In some instances, compounds not authorized under the permit, such as chloroform, were released.	Based on risk assessment/characterization of the WWTA, no corrective action is warranted.



Table 3
Corrective Action Objectives - Production Area Soil
Corrective Measures Study

BASF
Cranston, Rhode Island

Production Area - Soil			
Compound	MPS	RIDEM Industrial / Commercial Direct Exposure Criterion	RIDEM GB Leachability Criteria
Total PCBs	50	10	10
Non-PCB COCs		As specified in Remediation Regulations	As specified in Remediation Regulations



Table 4
Corrective Action Objectives - Production Area Groundwater
Corrective Measures Study

BASF
Cranston, Rhode Island

Production Area Groundwater		
VOCs (µg/L)	MPS	RIDEM GB Groundwater Objective
Toluene	1,700	1,700
2-Chlorotoluene	1,500	--
1,2-Dichlorobenzene	94	--
Chlorobenzene	1,700	3,200
Total xylenes	76	--

Notes:

— No GB Groundwater Objective exists

Other COCs in groundwater are subject to GB Groundwater Objectives



Table 5
Corrective Action Objectives - Pawtuxet River Sediment
Corrective Measures Study

BASF
Cranston, Rhode Island

Pawtuxet River Sediment - Interim Remedial Measures (IRM)		
Approach	Area	Date
Dredging/Capping	Adjacent to bulkhead, west of former train bridge (Figure 8, Figure 12)	1996 (Woodward Clyde)
Sediment Dredging/Capping	Three locations adjacent to bulkhead (Figure 8) - 23 CY of sediment removed. Backfilled with fine sand to restore the river bottom to natural grade.	2011 (AECOM)
Pawtuxet River Sediment - Corrective Action Objectives - Monitoring Plan		
Monitoring Frequency	Approach	Note
Every 5 yrs	Sand Cap Sampling	If PCBs are found at concentrations >10 ppm, additional investigation is warranted.
After every major flood event*	Sand Cap Sampling	If PCBs are found at concentrations >10 ppm, additional investigation is warranted.

Notes:

Major flood events occur where the Pawtuxet River stage at Cranston monitoring station CRAR1 exceeds 13 feet (NOAA).
(For context, the 2010 floods reached 20.2 feet)



Table 6
Soil Remediation Technologies - Production Area
Corrective Measures Study

BASF
Cranston, Rhode Island

Production Area Soil		
Technologies Screened	Concerns with Technology	Consideration
No Action	Does not address impacts	Retained only for comparative analysis
Institutional and Engineering Controls		
Environmental Land Use Restriction	Restricts use, does not remove impacts	Retained for further evaluation
Engineered Controls	Physically isolates to reduce human health exposure and/or environmental impacts, but does not remove impacts	Retained for further evaluation
Ex Situ Treatment Technologies		
Excavation and Off-Site Disposal	Technology will address PCBs, but may be cost prohibitive	Retained for further evaluation
Excavation and On-Site Reuse	Technology may be applicable only for lower concentrations of PCBs	Retained for further evaluation
In Situ Treatment Technologies		
In Situ Thermal Destruction	Technology would need to be accepted by Agency and could be cost prohibitive	Not retained for further evaluation



Table 7
Groundwater Treatment Technologies Screening - Production Area
Corrective Measures Study

BASF
Cranston, Rhode Island

Mill Street-Groundwater		
Technologies Screened	Concerns with Technology	Consideration
No Action	Does not address impacts	Retained only for comparative analysis
Institutional and Engineering Controls		
Environmental Land Use Restriction	Restricts use, does not address impacts	Retained for further evaluation
Engineered Controls	Physically isolates to reduce human health exposure and/or environmental impacts, but does not remove impacts	Retained for further evaluation
Monitored Natural Attenuation	Does not treat impacts, monitoring is performed to evaluate potential exposure risks and contaminant reduction	Retained for further evaluation
In Situ Treatment Technologies		
In Situ Chemical Reduction	Not anticipated to be able to treat all site COCs.	Not retained for further evaluation
In Situ Chemical Oxidation	Applicable to COCs in groundwater, need to distribute amendment properly	Retained for further evaluation
In Situ Enhanced Microbial Reduction	Based on bench-scale tests, kinetics of treatment are too low or ineffective for site COCs	Not retained for further evaluation
In Situ Aerobic Biodegradation	Applicable to COCs in groundwater, need to distribute oxygen properly	Retained for further evaluation
Air Sparge / Soil Vapor Extraction (SVE)	Pilot test of this technology in 2011 indicated that Site was not amenable to successful treatment by SVE	Not retained for further evaluation
Ex Situ Treatment Technologies		
Groundwater Extraction and Treatment	Applicable to COCs in groundwater, but does not destroy COCs and may be cost prohibitive due to extended operation timeframe	Retained for further evaluation



Table 8
Former Waste Water Treatment Area - Site Wide Corrective Action
Corrective Measures Study

BASF
Cranston, Rhode Island

Former Waste Water Treatment Area - Site Wide Technologies		
Technologies Screened	Concerns with Technology	Consideration
No Further Action	The property was sold in 2004. To date, the USEPA has not issued a Statement of Basis outlining the regulatory decision on the property, and as such, it remains part of this CMS. Exceedances are located within the 200-foot riverbank wetlands zone, which precludes development and soil management without RIDEM approval. Further, a human health risk assessment completed in 1995 (Ciba, 1995) determined that there was no significant risk for a conservative future use scenario of an on-site resident (despite the commercial zoning designation).	This is the anticipated remedy for the Former Waste Water Treatment Area
Environmental Land Use Restriction	Restricts use, does not remove impacts	While this remedy was initially retained during the CMS Workplan, after further consideration was not retained because the property is currently not owned by BASF, therefore BASF cannot obtain an ELUR for the property.



Table 9
Summary of Soil Remediation Options - Production Area Soil
Corrective Measures Study

Remedial Option	Remedial Goals	Remedial Measures	Permitting	Approval Comments	Excavation/On-Site Reuse/Clean Fill-Cap Volumes (CY)	Cost	Implementability
Strictest Remedial Option (Unrestricted Use)	Removal of soil with PCBs ≥1 mg/kg Removal of soil with impacts exceeding state DEC No capping required	Soil excavation, no capping required, and no long-term site restrictions	State wetlands agency because work performed within buffer zone Planning agency because excavation within 100-yr flood plain No USACE permit	Readily approvable by federal and state authorities	8600/900/7600	\$6.4 MM	Readily implementable with known technologies, however, difficulty may arise working in and around subsurface structures.
State and Federal Self-Implementing Option (High Occupancy Use)	Removal of soil with PCBs ≥10 mg/kg Removal of soil with VOC impacts exceeding DEC and potential groundwater source Capping with 2' of clean soil	Soil excavation and capping with site use restrictions (no site use restrictions but no intrusive activities), subsurface structures remain	State wetlands agency because work performed within buffer zone Planning agency because excavation within 100-yr flood plain No USACE permit	Approvable by federal and state authorities Cap permeability requirements apply. Variation from this requires EPA approval	6300/3300/6400 *Final volumes may change based on pre-design investigation and/or confirmatory sampling. Volumes presented above represent one such high occupancy reuse scenario.	\$4.0 MM	Readily implementable with known technologies, however, difficulty may arise working in and around subsurface structures.
Risk Based Remediation (Low Occupancy Use)	Removal of soil with PCBs ≥50 mg/kg Removal of soil with VOC impacts exceeding DEC and potential groundwater source Capping with 2' of clean soil.	Soil excavation and capping with site use restrictions (low occupancy and no intrusive activities), subsurface structures remain	State wetlands agency because work performed within buffer zone Planning agency because excavation within 100-yr flood plain No USACE permit	For state, approval under RIDEM Tier III will be needed Remedial option has been discussed with federal regulators previously and fits into PCB self-implementing options if the site is limited in future use To avoid future site use restrictions future use would need to be defined and limited in activity Cap permeability requirements apply. Variation from this requires EPA approval	2400/1200/5600 *1,200 Tons of Foundations/Structures Removed	\$2.3 MM	Readily implementable with known technologies, however, difficulty may arise working in and around subsurface structures.



Table 10
Comparison of Soil Remedial Technologies - Production Area
Corrective Measures Study

Remedial Alternative	Overall Protection of Human Health and the Environment	Attainment of Media Cleanup Standards	Controls the Sources of Releases	Long Term Reliability and Effectiveness	Reduction in Toxicity, Mobility, or Volume of Wastes	Short Term Effectiveness	Implementability and Environmental Footprint	Cost	Federal, State and Community Acceptance	Score
No Action										
No Action	6	6	6	6	6	1	1	1	6	39
Institutional and Engineering Controls										
Environmental Land Use Restriction	5	5	5	5	5	2	2	2	5	36
Engineered Controls	4	4	4	4	4	3	3	3	4	33
Ex Situ Treatment Technologies										
Excavation and Off-Site Disposal/On-Site Reuse										
Strictest Remedial Standard >1 PPM	1	1	1	1	1	6	6	6	1	24
>10 PPM*	2	2	2	2	2	5	5	5	2	27
>50 PPM*	3	3	3	3	3	4	4	4	3	30

Notes:
Scoring System: 1 = Best / 6 = Worst
*Includes on-site reuse of some proportion of impacted soil



Table 11
Description of Retained Groundwater Treatment Technologies - Production Area
Corrective Measures Study

Remedial Alternative	Reagent	Safety/Odor Issues	Effectiveness for Treatment of Benzene, Toluene and Xylenes	Effectiveness for Treatment of Chlorobenzene and 1,2-Dichlorobenzene	Effectiveness for Treatment of 2-Chlorotoluene	Site-Specific Implementation	Estimated Costs	Other Concerns
No Action								
No Action	None	None	Not Effective			No actions are implemented at the Site.	\$0	Not protective of the environment.
Institutional and Engineering Controls								
Environmental Land Use Restriction	None	None	Restricts current and future use of the Site to limit potential exposure to groundwater and soil vapor (where applicable).			Restricts future use of the Site and Site groundwater	\$800K	Does not prevent impacted groundwater from reaching the Pawtuxet River.
Engineered Controls	None	None	Means of physical isolation to reduce human health exposure and/or environmental impacts.			Construct an impermeable cap over areas of shallow groundwater impacts to prevent further degradation of groundwater quality. Use sheet pile to encompass plume.	\$4.0MM	Does not treat COCs. Would likely require extensive monitoring for extended time frames.
Monitored Natural Attenuation								
Monitored Natural Attenuation	None	None	Mass, toxicity, mobility, volume, and/or concentrations of COCs are reduced by natural physical, chemical, and/or biological processes.			<ul style="list-style-type: none">• Baseline monitoring of site COCs,• Implement other remedies (if applicable),• Periodic monitoring, and• Periodic review of progress toward remedial goals.	\$1MM	Depends on aquifer conditions and availability of microbial community to degrade contaminants. Based on Site data, microbial communities are present, but will take many years to achieve remedial goals.
In Situ Technologies								
In-Situ Chemical Oxidation	Ozone Barrier/Residual Source Treatment/MNA	Medium	Good	Good	Good	Effectiveness depends on good distribution. A byproduct of ozone degradation is oxygen, and based on degradation rates there is limited concern for oxidant discharge to the river.	\$2.3MM	Requires continuous air/ozone sparging in a barrier geometry adjacent to the Pawtuxet River. Also included an ISCO residual source zone treatment and MNA of mid-plume areas.
		Oxidizer, closely monitor breathing space	ITRC and EPA guidance documents suggest good to excellent effectiveness	EPA Engineering ISCO guidance document suggests excellent effectiveness	Direct data not examined, but chemical similarity of 2-chlorotoluene to 1,2-dichlorobenzene suggests medium to good oxidant effectiveness			Oxygen is a byproduct of degradation which would stimulate aerobic degradation
Aerobic Biodegradation	Oxygen Sparge Barrier/Residual Source Treatment/MNA	Good	Good	Good	Medium	Complete degradation pathways are present for all COCs with MPS criteria developed. Requires the introduction and maintaining of adequate dissolved oxygen in groundwater. Bench scale tests showed some degradation of chlorinated ethenes and the literature support this, however, this should be confirmed in the field during pilot testing.	\$1.4MM	Requires diffusion of DO supersaturated groundwater in a barrier geometry adjacent to the Pawtuxet River. Also included an ISCO residual source zone treatment and MNA of mid-plume areas.
		None	Aerobic biodegradation is well known to oxidize BTEX	Aerobic biodegradation is well known to oxidize CBs	Aerobic biodegradation is known to oxidize 2-CT			The aquifer is currently anaerobic, so aerobic conditions would need to be established and maintained for aerobic biodegradation to occur.
Ex Situ Treatment Technologies								
Groundwater Pump and Treat	None	Good	Medium	Medium	Medium	Pump and treat infrastructure will need repairs, additional wells.	\$7.6MM	May not effectively treat residual source in heterogeneous/low permeability materials. Treatment time frames are dependent on rate-limited mass transfer where high COC concentrations are present in heterogeneous media and will require the system to run for a very long time.
		None	Adsorption by GAC/air stripping is well known to treat BTEX compounds	Adsorption by GAC is known to treat chlorinated compounds	Adsorption by GAC is known to treat chlorinated compounds			



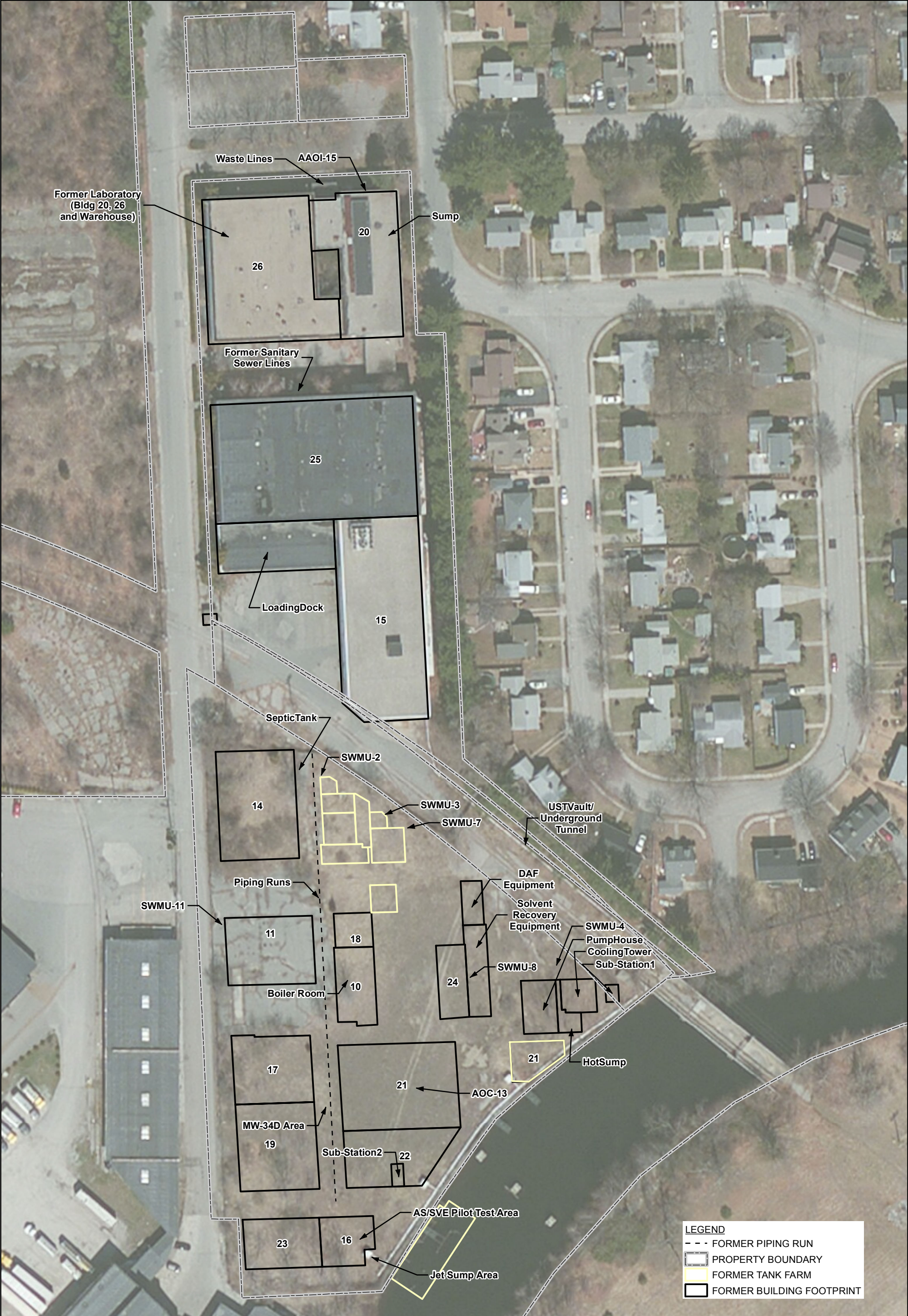
Table 12
Comparison of Groundwater Remedial Technologies - Production Area
Corrective Measures Study

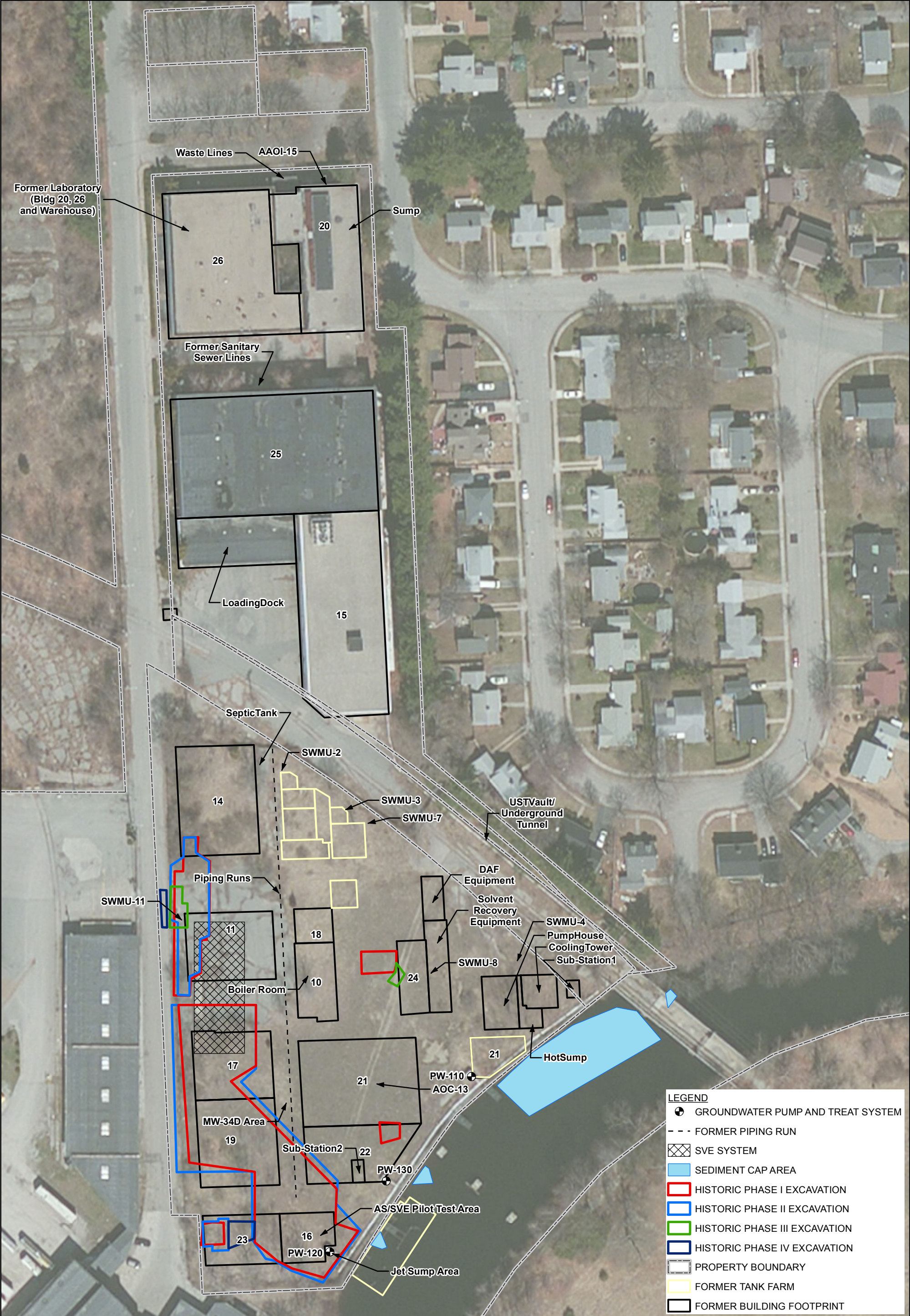
Remedial Alternative	Overall Protection of Human Health and the Environment	Attainment of Media Cleanup Standards	Controls the Sources of Releases	Long Term Reliability and Effectiveness	Reduction in Toxicity, Mobility, or Volume of Wastes	Short Term Effectiveness	Implementability and Environmental Footprint	Cost	Federal, State and Community Acceptance	Score
No Action										
No Action	7	7	7	7	7	1	1	1	7	45
Institutional and Engineering Controls										
Environmental Land Use Restriction	6	6	6	6	6	2	2	2	6	42
Engineered Controls	4	5	3	3	5	7	6	6	4	43
Monitored Natural Attenuation										
Monitored Natural Attenuation	5	4	5	5	4	3	3	3	5	37
Ex Situ Treatment Technologies										
Groundwater Pump and Treat	3	3	4	4	3	4	7	7	3	38
In Situ Treatment Technologies										
In Situ Chemical Oxidation	1	1	1	1	1	5	5	5	1	21
In Situ Aerobic Biodegradation	2	2	2	2	2	6	4	4	2	26

Notes:
Scoring System: 1 = Best / 7 = Worst

Figures

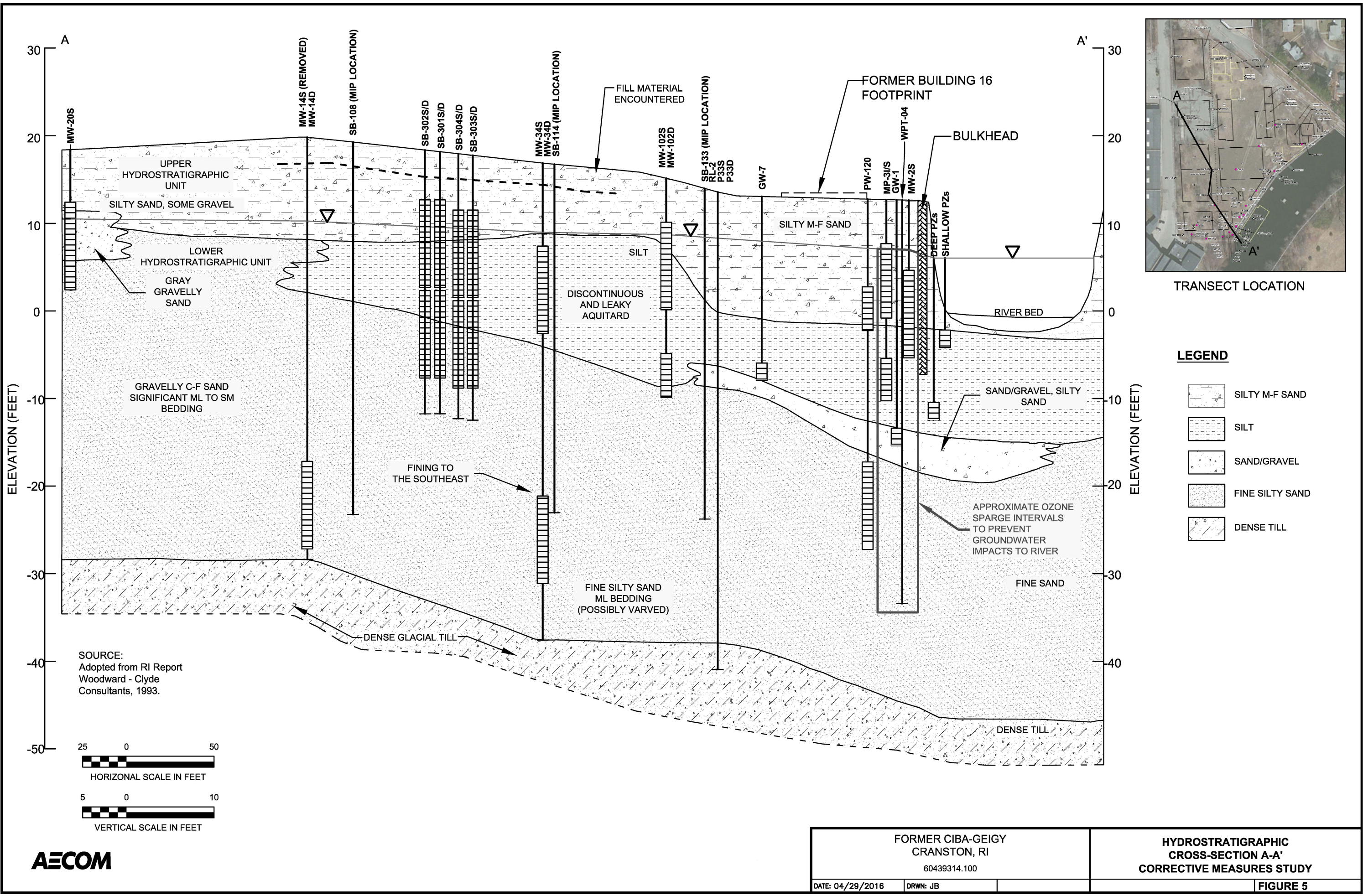




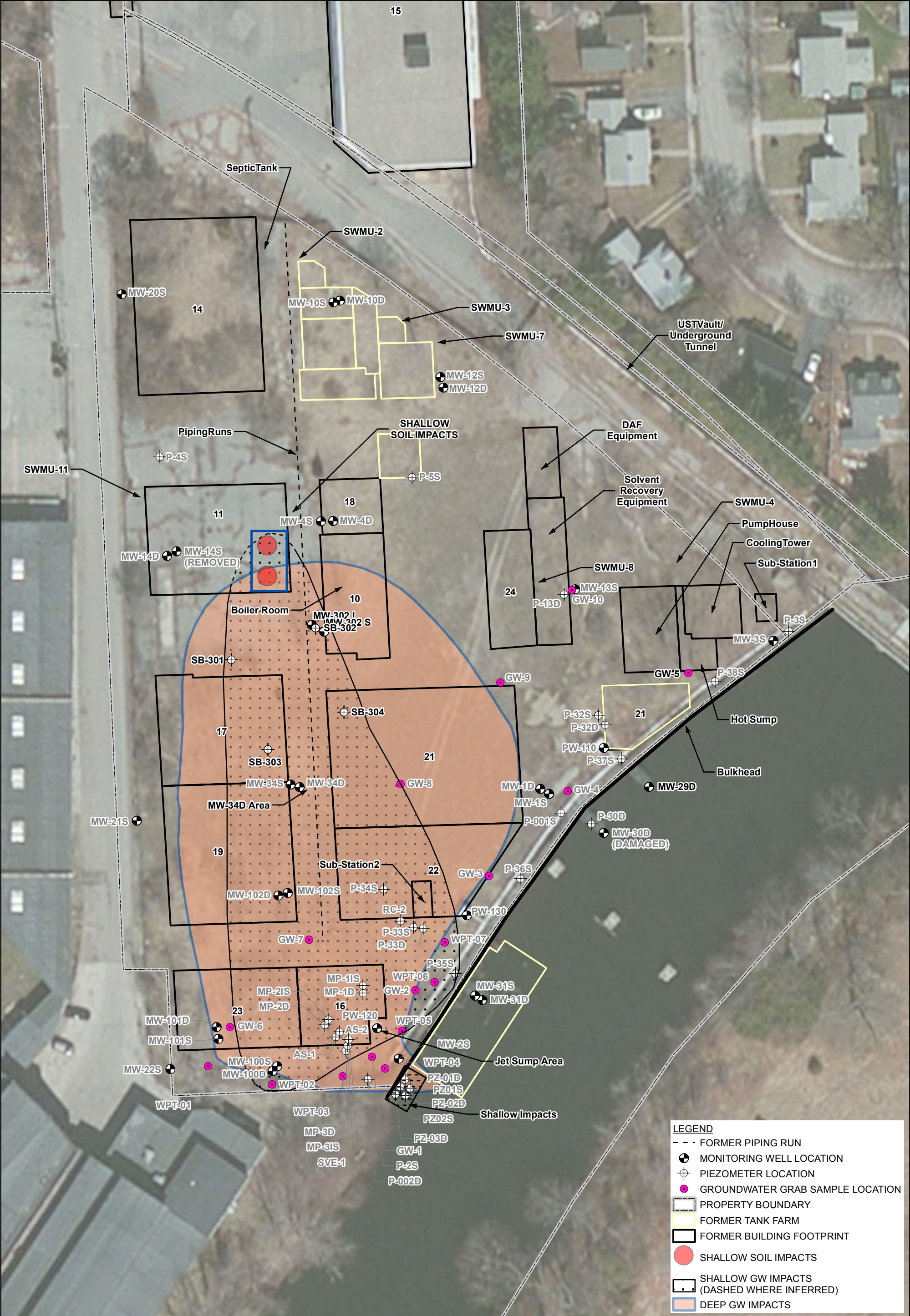


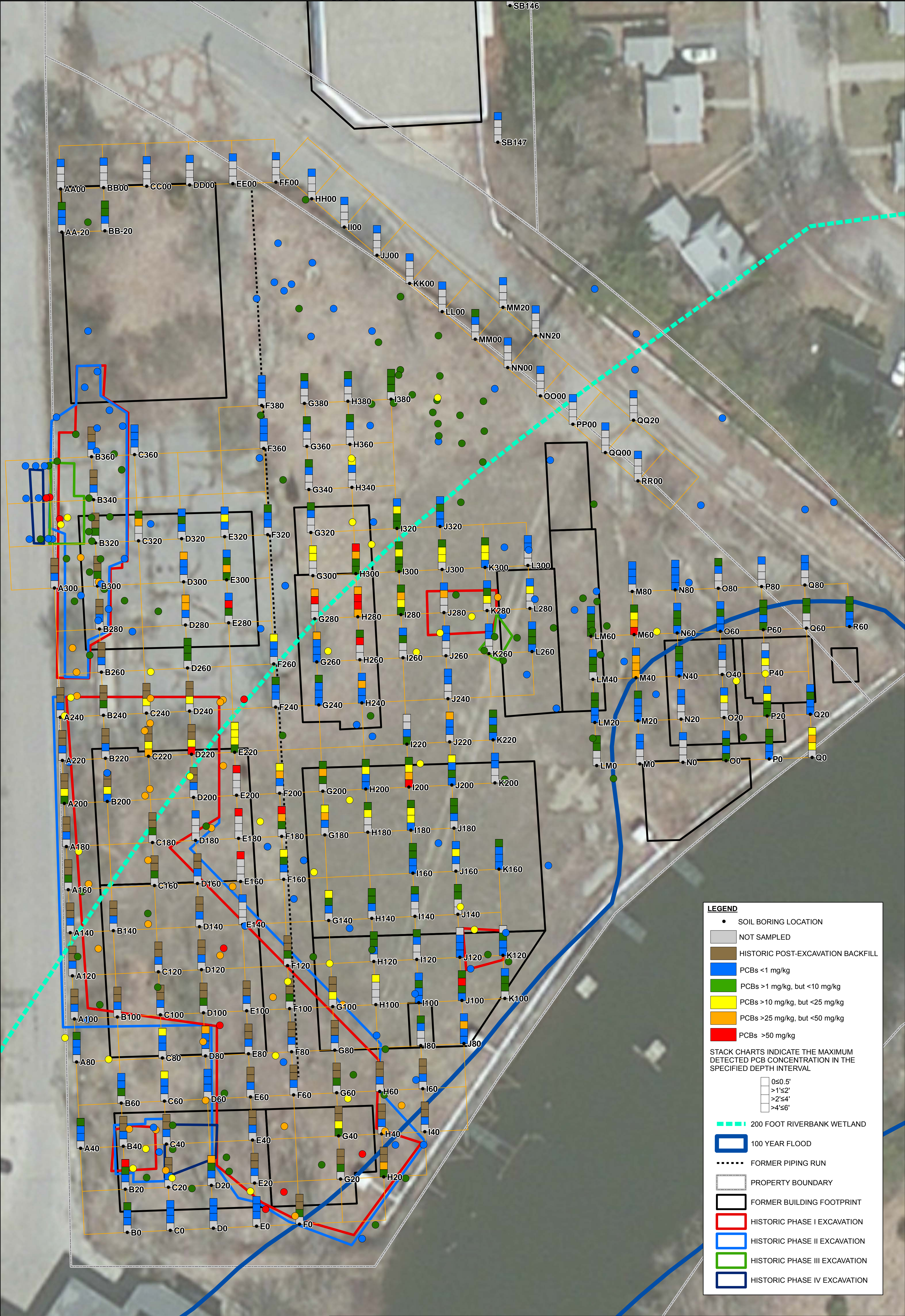


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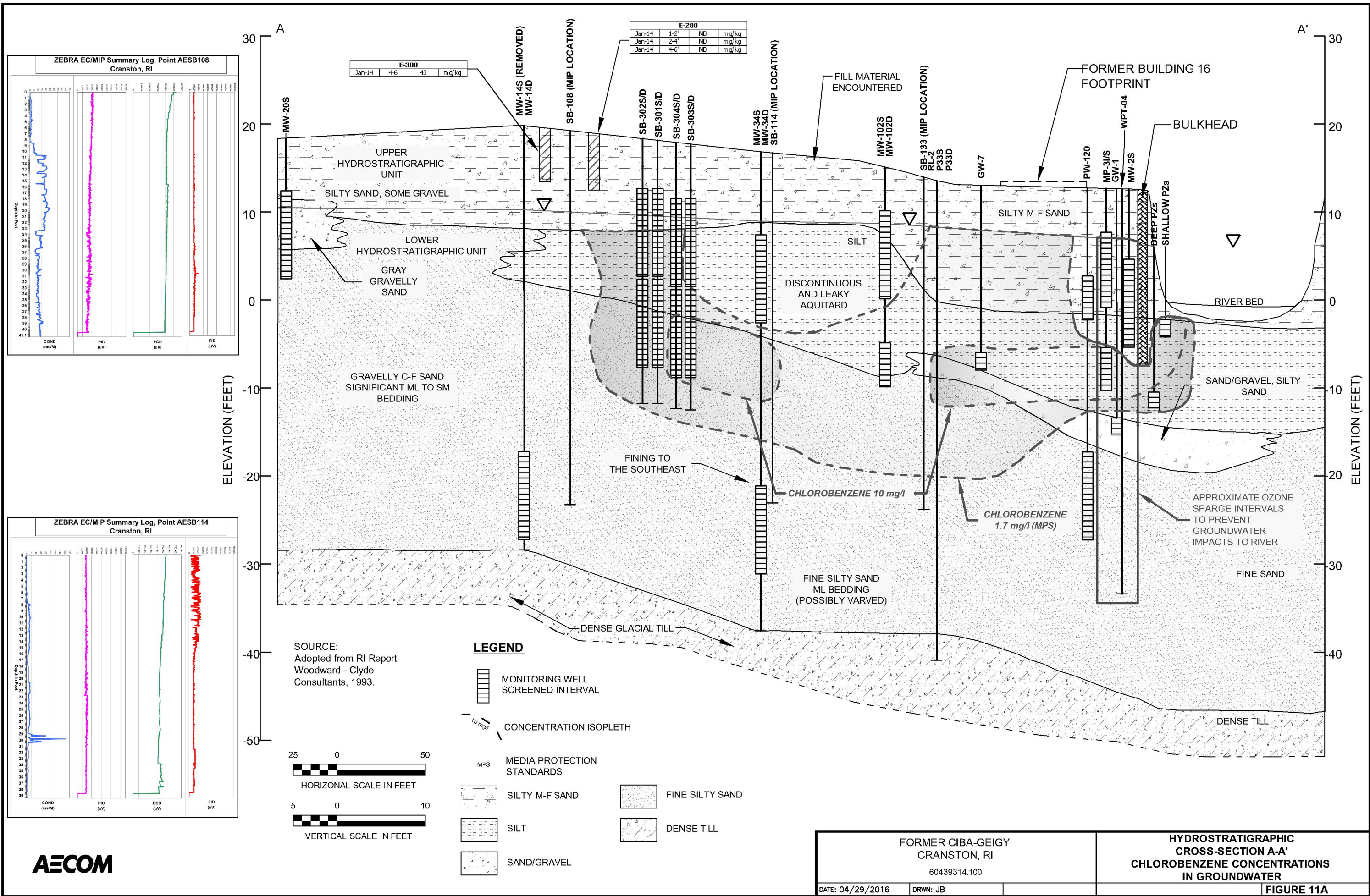




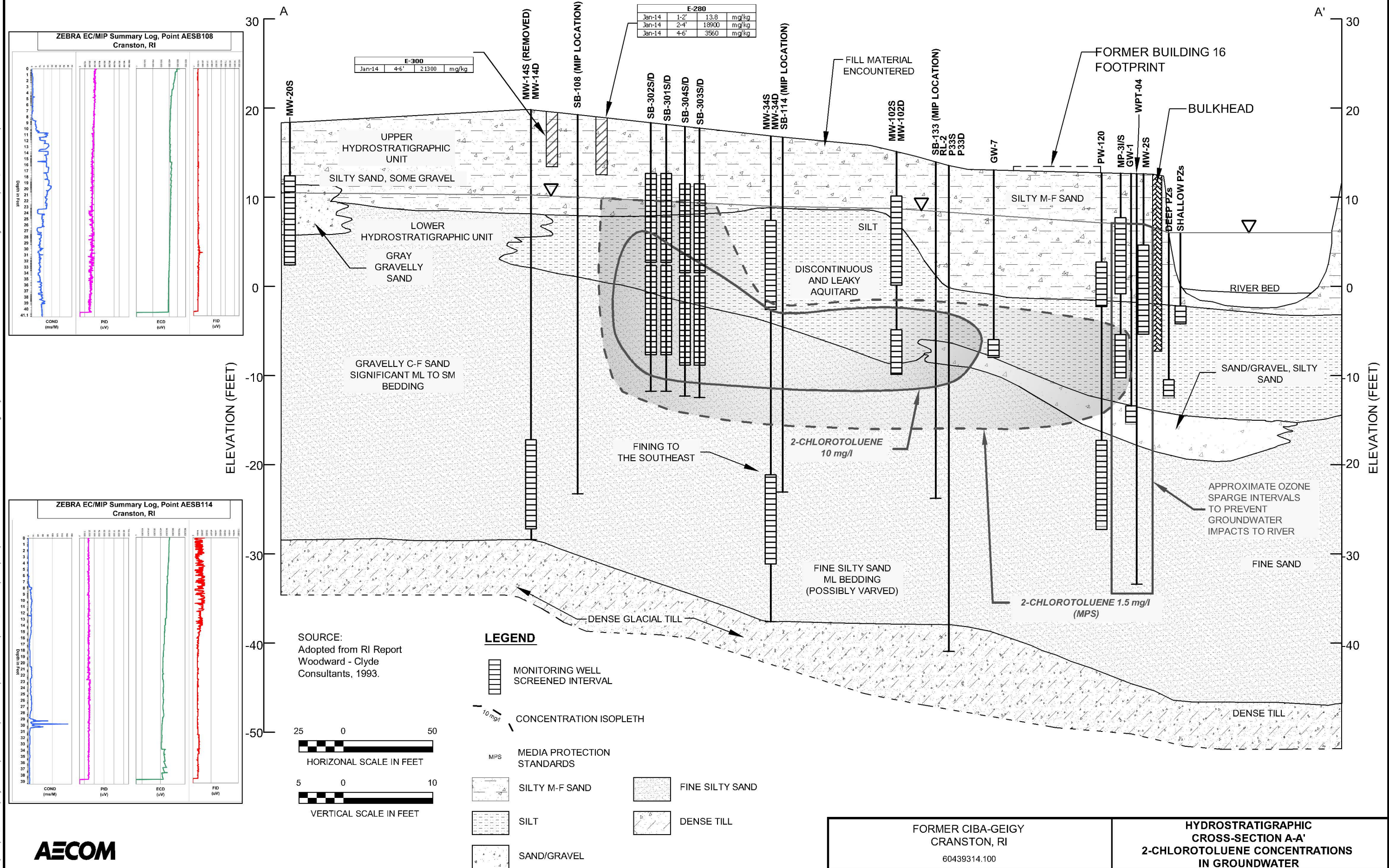




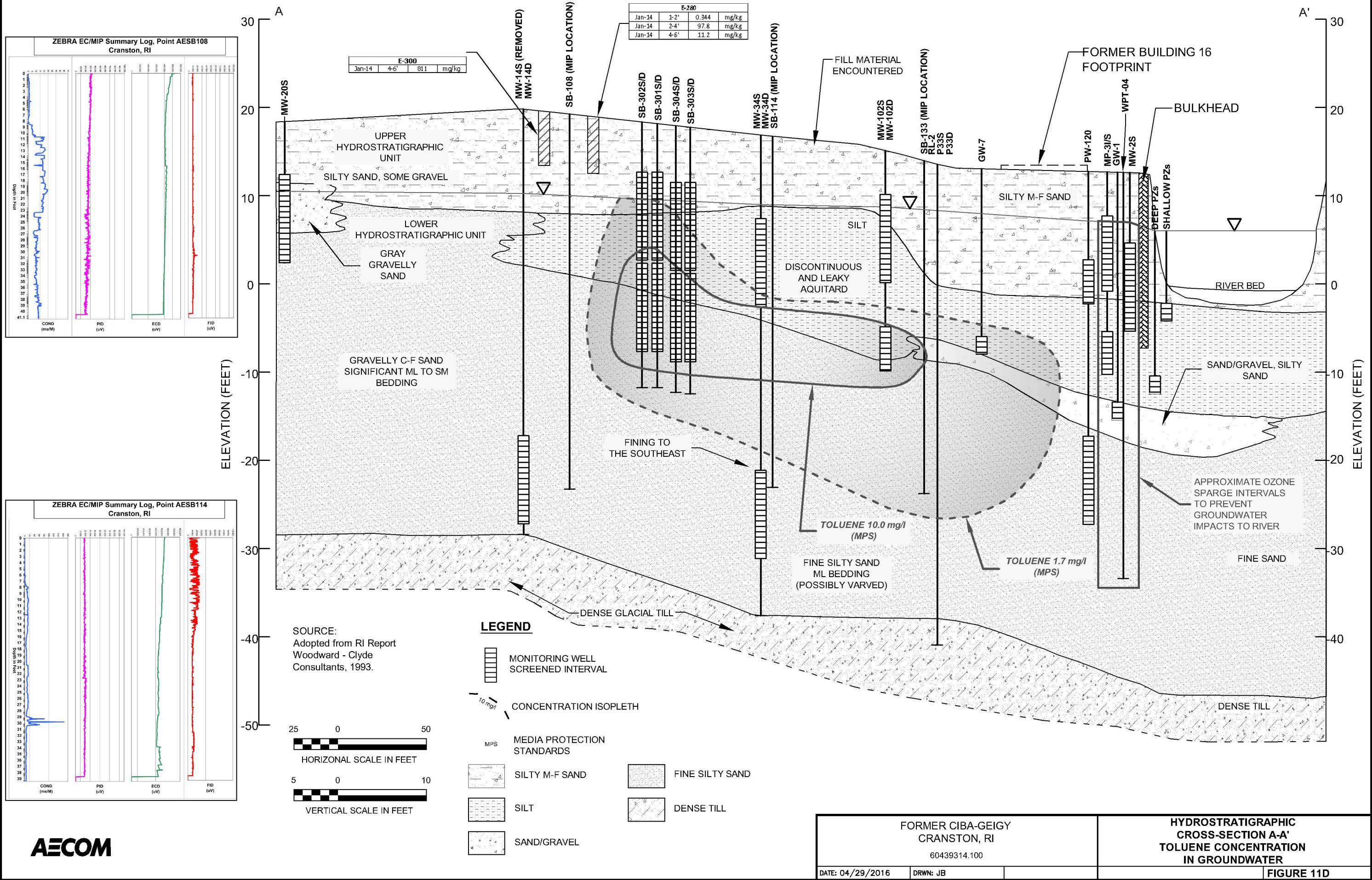
File: P:\Jobs\Incl_Service\Project_Files\BASF-0760\Cranston_RI\Z_Deliverables\1_GIS_Database\CAUD\CMS\HYDROSTRATIGRAPHY_CROSS_SECTIONS.dwg Layout: FIGURE 11A CHLOROBENZENE User: bourdeauj Plotted: Apr 29, 2016 - 1:55pm Xref's:



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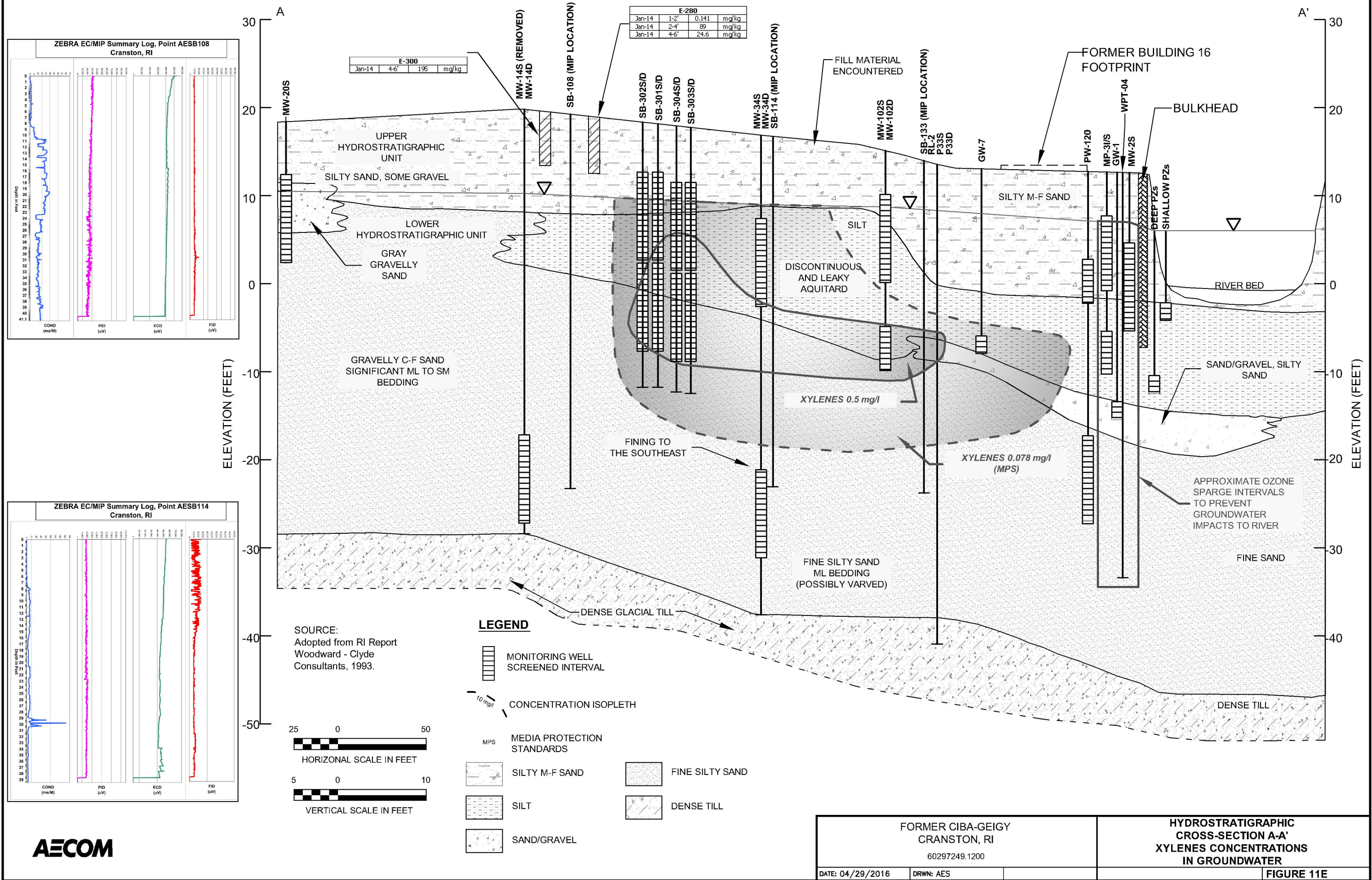


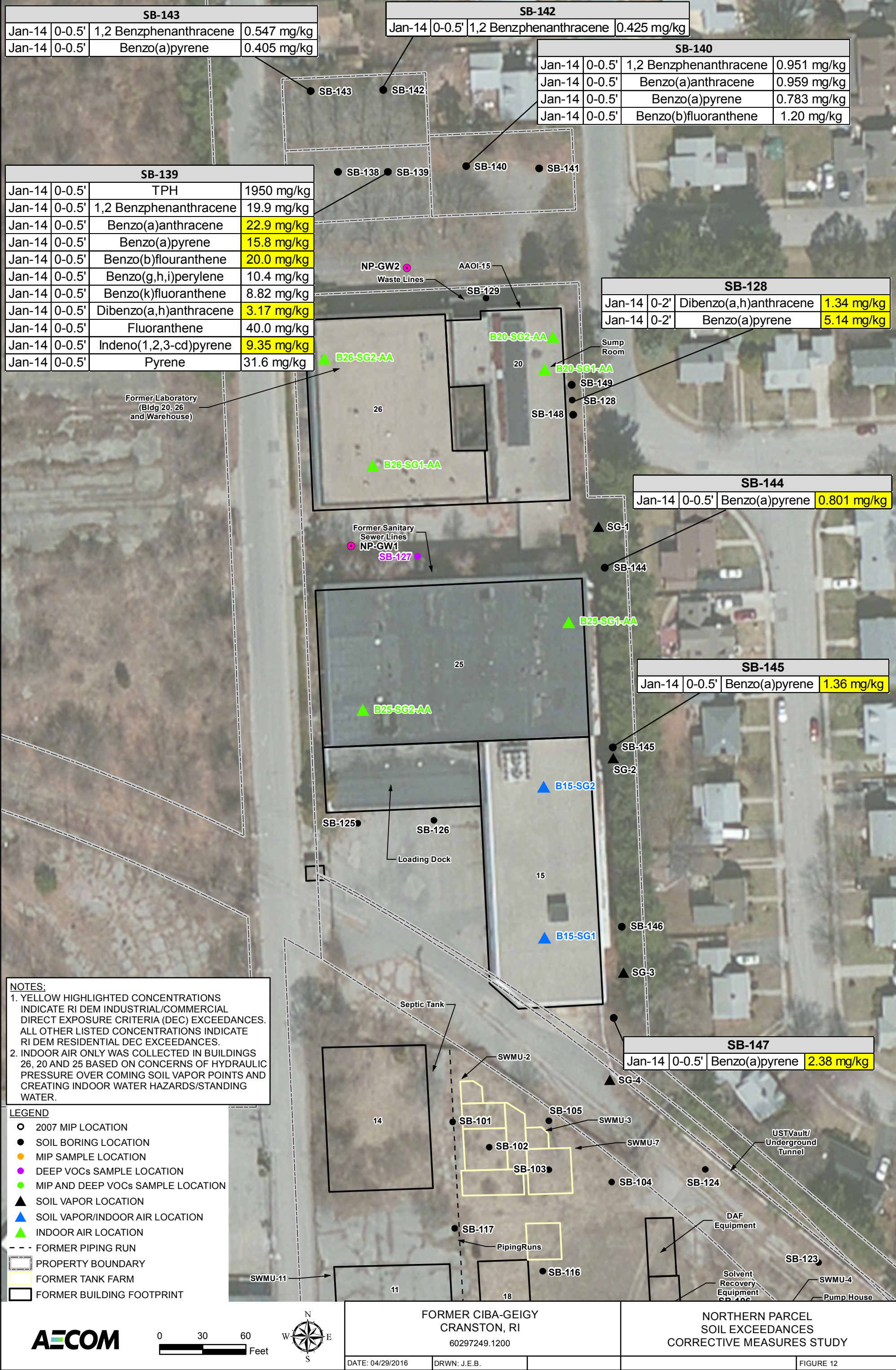
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AECOM

File: P:\Jobs\Invt_Service\Project_Files\BASF-0780\Cranston_RI\Z_Deliverables\1_GIS_Database\CAUD\CMS\HYDROSTRATIGRAPHY_CROSS_SECTIONS.cmg Layout: FIGURE 11E XYLENES User: bourdeauj Plotted: Apr 29, 2016 - 2:10pm Xref's:







FORMER WWTA PROPERTY BOUNDARY

HISTORIC SOIL SAMPLE LOCATION

100 YEAR FLOOD

0

0 50 100

		Feet
--	--	------

60297249.1200

t	DATE: 04/29/2016
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DRWN: J.E.B.

FORMER WASTEWATER TREATMENT AREA
CORRECTIVE MEASURES STUDY

FIGURE 13

Path: P:\Jobs\Indl_Service\Project Files\BASF-0760\Cranston RI\7_Deliverables\1. GIS_Database\Projects\CMIS\MXD\Figure_15_Cap_Integrity_Monitoring_Plan.mxd

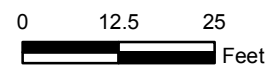


LEGEND

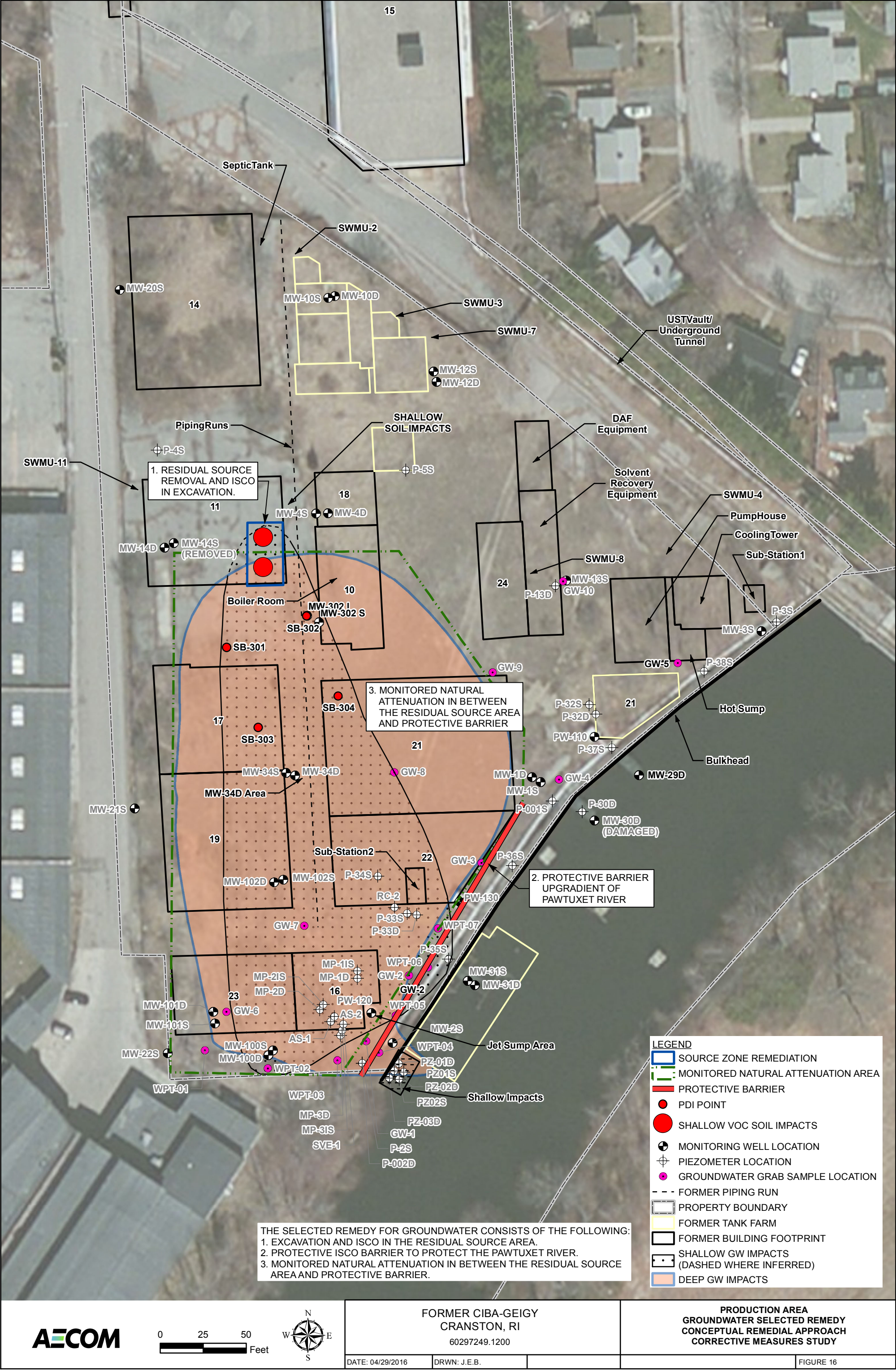
- Cap Monitoring Area
- CAP AREA
- Property Boundary



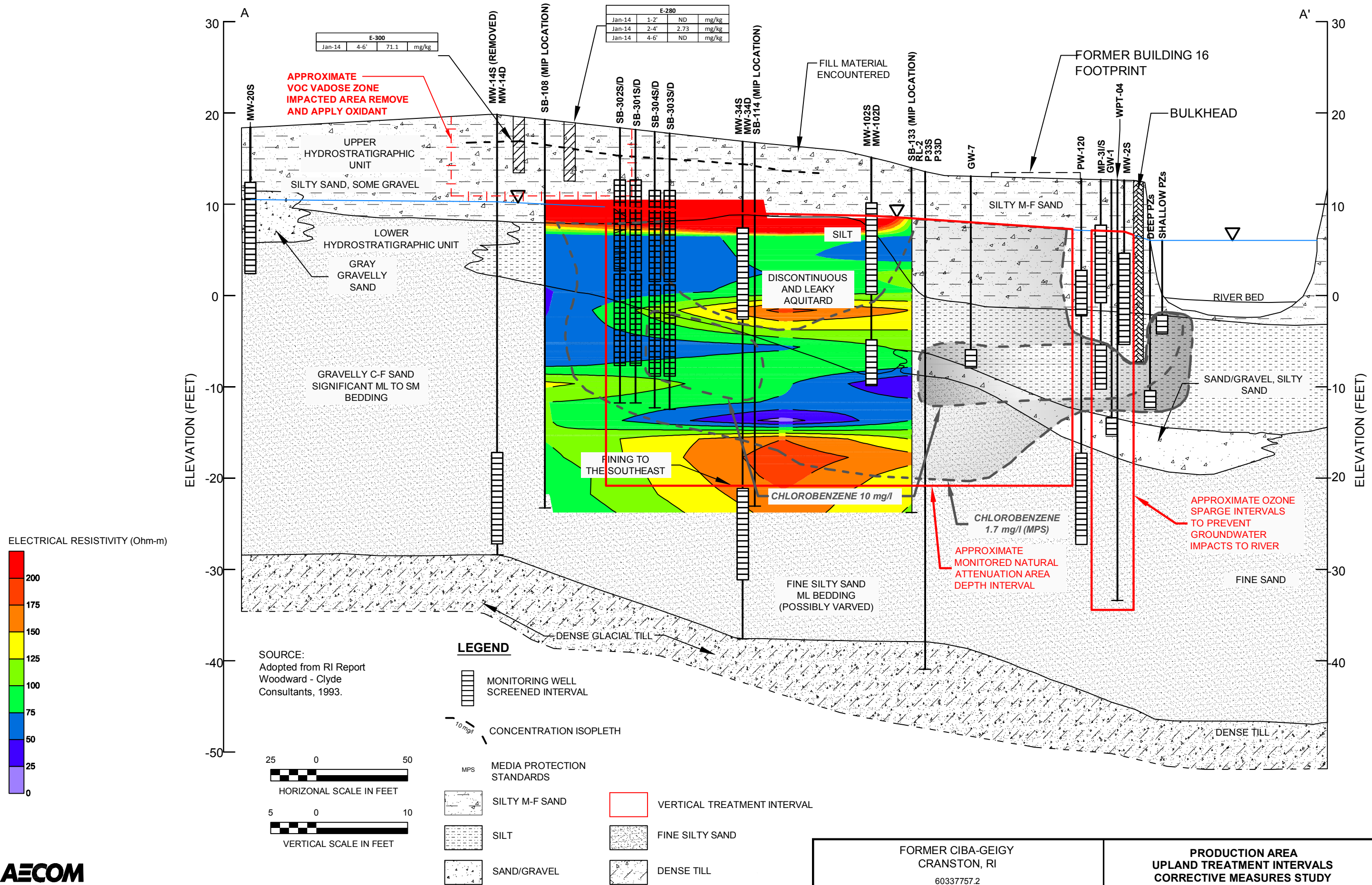
SOURCES:
1. AERIAL PHOTOGRAPHY FROM ESRI.
2. PROPERTY BOUNDARY FROM CITY OF CRANSTON, RHODE ISLAND ASSESSMENT MAP 4-5.
3. RFI REPORT, PAWTUXET RIVER, WOODWARD-CLYDE, MARCH 1996



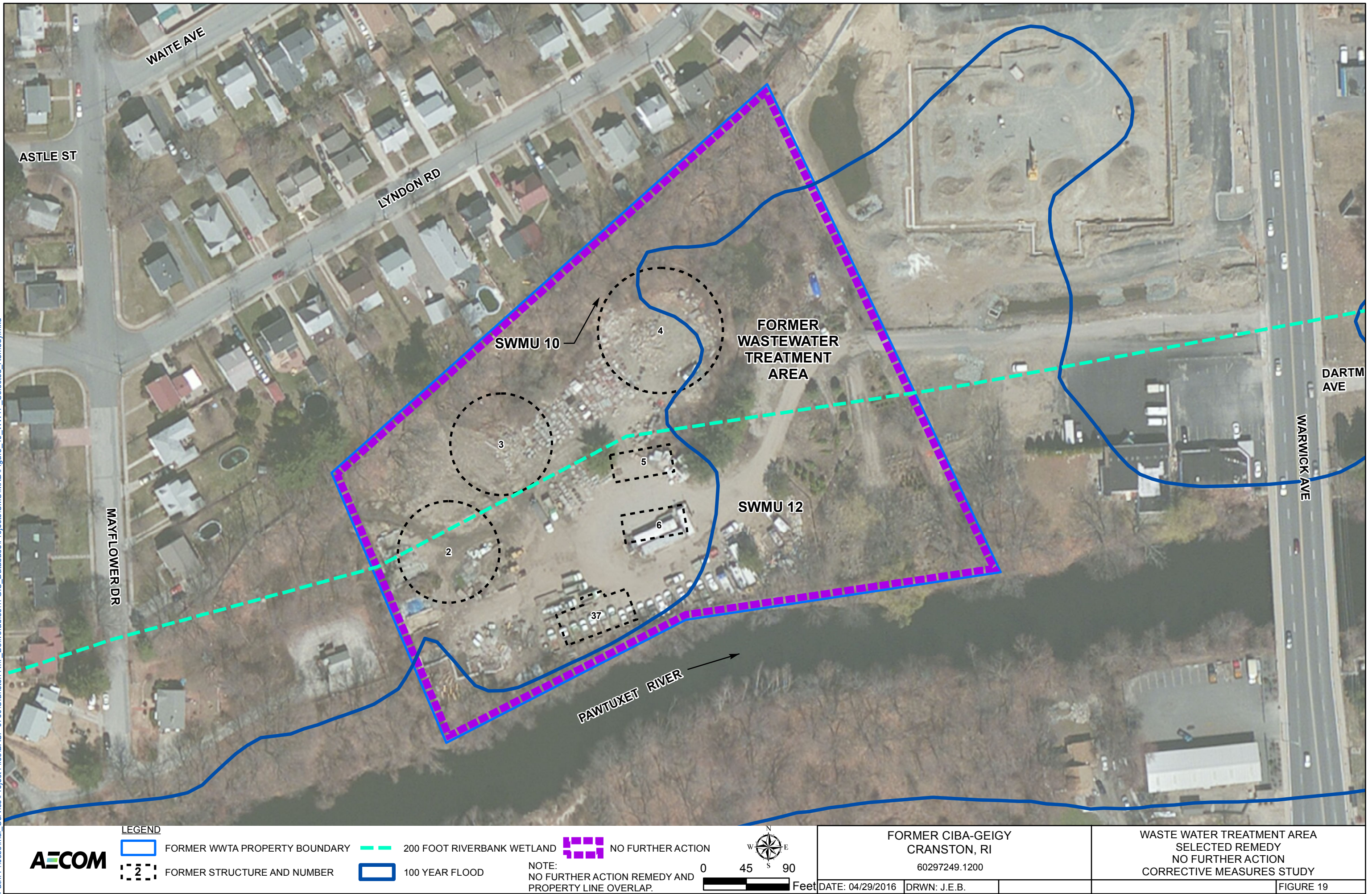
FORMER CIBA-GEIGY CRANSTON, RI 60297249.1500			PAWTUXET RIVER SEDIMENT CAP INTEGRITY MONITORING PLAN CORRECTIVE MEASURES STUDY	
DATE: 04/29/2016	DRWN: KNH			FIGURE 15



File: P:\Jobs\Ind_Service\Project_Files\BAST-0760\Cranton RI\Z_Deliverables\1_GIS_Database\CADD\CMS\HYDROSTRATIGRAPHY_CROSS_SECTIONS.dwg Layout: FIGURE 17 VERTICAL TREATMENT User: bourdeauj Plotted: Apr 29, 2016 - 2:13pm Xref's:



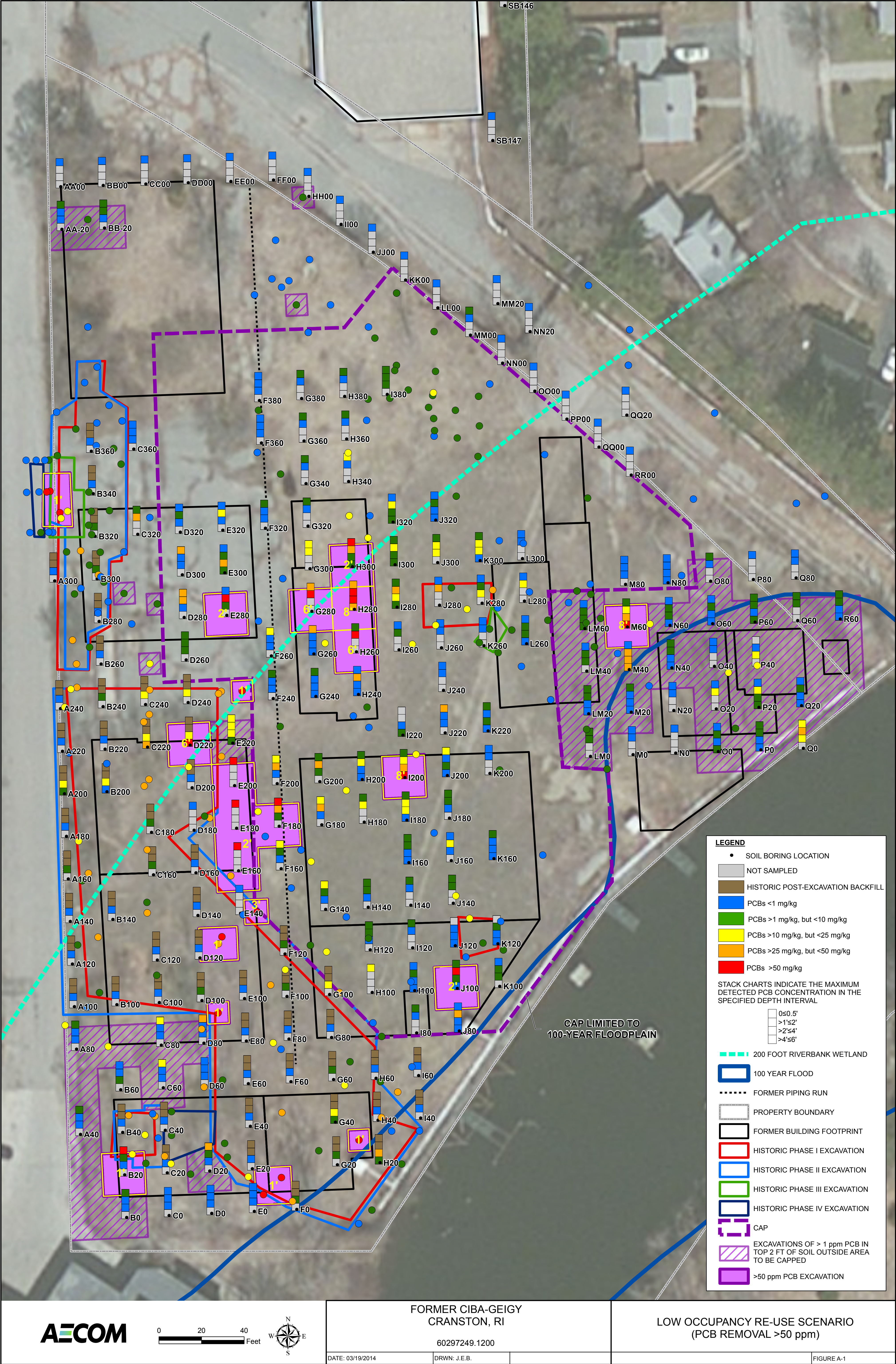
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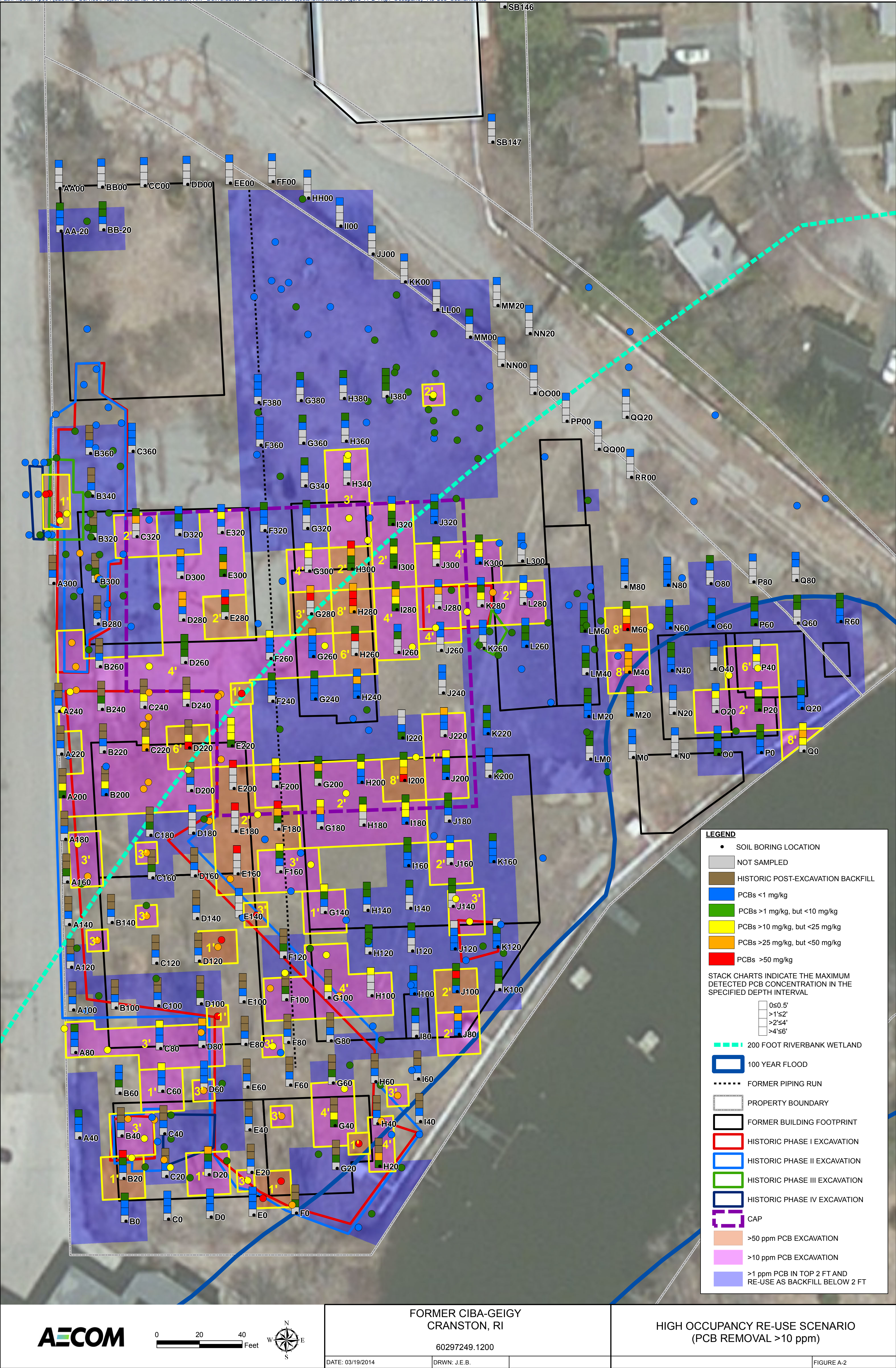


Appendix A

Soil Remedial Options – Conceptual Design Figures

- Figure A-1 – Low Occupancy Re-Use Scenario (PCB Removal >50 ppm) –
- Figure A-2 – High Occupancy Re-Use Scenario (PCB Removal >10 ppm)
- Figure A-3 – Strictest Remedial Standard (PCB Removal >1 ppm)
- Figure A-4 – Northern Parcel Areas Remedial Options





Appendix B

Soil Remedial Options - Conceptual Design Volume Calculations

Low Occupancy Future Use Scenario
Removal of PCBs > 50 ppm
Corrective Measures Study
Former Ciba-Geigy Facility
Cranston, RI

Table B-1A Excavation of > 50 ppm PCBs

Area of Property	Interval								# Confirmation Samples	Soil to be Disposed
	0-1'	0-2'	0-3'	0-4'	0-6'	0-8'	2-4'	4-6'		
3 Red Dots North of A300										
Depth of Excavation	1									
Area (SF)/Excavation cell	400								16	
Number of Cells to be Excavated	1									
Cubic Feet/Excavation cell	400	0	0	0	0	0				
Cubic Yards/Excavation cell	15	0	0	0	0	0				
Tons/Excavation cell	24	0	0	0	0	0				
Total CY	15	0	0	0	0	0				15
Total Tons	24	0	0	0	0	0				24
E280										
Depth of Excavation		2								
Area (SF)/Excavation cell		400							16	
Number of Cells to be Excavated		1								
Cubic Feet/Excavation cell	0	800	0	0	0	0				
Cubic Yards/Excavation cell	0	30	0	0	0	0				
Tons/Excavation cell	0	47	0	0	0	0				
Total CY	0	30	0	0	0	0				30
Total Tons	0	47	0	0	0	0				47
D220										
Depth of Excavation					6					
Area (SF)/Excavation cell					400				16	
Number of Cells to be Excavated					1					
Cubic Feet/Excavation cell	0	0	0	0	2400	0				
Cubic Yards/Excavation cell	0	0	0	0	89	0				
Tons/Excavation cell	0	0	0	0	142	0				
Total CY	0	0	0	0	89	0				89
Total Tons	0	0	0	0	142	0				142
B20										
Depth of Excavation	1									
Area (SF)/Excavation cell	400								16	
Number of Cells to be Excavated	1									
Cubic Feet/Excavation cell	400	0	0	0	0	0				
Cubic Yards/Excavation cell	15	0	0	0	0	0				
Tons/Excavation cell	24	0	0	0	0	0				
Total CY	15	0	0	0	0	0				15
Total Tons	24	0	0	0	0	0				24
Red Dot SE of D100										
Depth of Excavation	1									
Area (SF)/Excavation cell	100								4	
Number of Cells to be Excavated	1									
Cubic Feet/Excavation cell	100	0	0	0	0	0				
Cubic Yards/Excavation cell	4	0	0	0	0	0				
Tons/Excavation cell	6	0	0	0	0	0				
Total CY	4	0	0	0	0	0				4
Total Tons	6	0	0	0	0	0				6

**Low Occupancy Future Use Scenario
Removal of PCBs > 50 ppm
Corrective Measures Study
Former Ciba-Geigy Facility
Cranston, RI**

Table B-1A Excavation of > 50 ppm PCBs

Area of Property	Interval								# Confirmation Samples	Soil to be Disposed
	0-1'	0-2'	0-3'	0-4'	0-6'	0-8'	2-4'	4-6'		
Red/Orange Dot NE of D120										
Depth of Excavation	1									
Area (SF)/Excavation cell	100								4	
Number of Cells to be Excavated	1									
Cubic Feet/Excavation cell	100	0	0	0	0	0				
Cubic Yards/Excavation cell	4	0	0	0	0	0				
Tons/Excavation cell	6	0	0	0	0	0				
Total CY	4	0	0	0	0	0				4
Total Tons	6	0	0	0	0	0				6
E160/E180/E200/F180										
Depth of Excavation		2								
Area (SF)/Excavation cell		400							64	
Number of Cells to be Excavated		4								
Cubic Feet/Excavation cell	0	800	0	0	0	0				
Cubic Yards/Excavation cell	0	30	0	0	0	0				
Tons/Excavation cell	0	47	0	0	0	0				
Total CY	0	119	0	0	0	0				119
Total Tons	0	190	0	0	0	0				190
Red Dot NE of E220										
Depth of Excavation	1									
Area (SF)/Excavation cell	100								4	
Number of Cells to be Excavated	1									
Cubic Feet/Excavation cell	100	0	0	0	0	0				
Cubic Yards/Excavation cell	4	0	0	0	0	0				
Tons/Excavation cell	6	0	0	0	0	0				
Total CY	4	0	0	0	0	0				4
Total Tons	6	0	0	0	0	0				6
Two Red Dots NE of E0										
Depth of Excavation	1									
Area (SF)/Excavation cell	300								12	
Number of Cells to be Excavated	1									
Cubic Feet/Excavation cell	300	0	0	0	0	0				
Cubic Yards/Excavation cell	11	0	0	0	0	0				
Tons/Excavation cell	18	0	0	0	0	0				
Total CY	11	0	0	0	0	0				11
Total Tons	18	0	0	0	0	0				18
Red Dot NE of G20										
Depth of Excavation	1									
Area (SF)/Excavation cell	100								4	
Number of Cells to be Excavated	1									
Cubic Feet/Excavation cell	100	0	0	0	0	0				
Cubic Yards/Excavation cell	4	0	0	0	0	0				
Tons/Excavation cell	6	0	0	0	0	0				
Total CY	4	0	0	0	0	0				4
Total Tons	6	0	0	0	0	0				6

**Low Occupancy Future Use Scenario
Removal of PCBs > 50 ppm
Corrective Measures Study
Former Ciba-Geigy Facility
Cranston, RI**

Table B-1A Excavation of > 50 ppm PCBs

Area of Property	Interval								# Confirmation Samples	Soil to be Disposed
	0-1'	0-2'	0-3'	0-4'	0-6'	0-8'	2-4'	4-6'		
J100										
Depth of Excavation		2								
Area (SF)/Excavation cell		400							16	
Number of Cells to be Excavated		1								
Cubic Feet	0	800	0	0	0	0				
Cubic Yards	0	30	0	0	0	0				
Tons	0	47	0	0	0	0				
Total CY	0	30	0	0	0	0				30
Total Tons	0	47	0	0	0	0				47
I200										
Depth of Excavation						8				
Area (SF)/Excavation cell						400			16	
Number of Cells to be Excavated						1				
Cubic Feet/Excavation cell	0	0	0	0	0	3200				
Cubic Yards/Excavation cell	0	0	0	0	0	119				
Tons/Excavation cell	0	0	0	0	0	190				
Total CY	0	0	0	0	0	119				119
Total Tons	0	0	0	0	0	190				190
H300/H280/G280/H260										
Depth of Excavation		2			6	8				
Area (SF)/Excavation cell		400			400	400			64	
Number of Cells to be Excavated		1			2	1				
Cubic Feet/Excavation cell	0	800	0	0	2400	3200				
Cubic Yards/Excavation cell	0	30	0	0	89	119				
Tons/Excavation cell	0	47	0	0	142	190				
Total CY	0	30	0	0	178	119				326
Total Tons	0	47	0	0	284	190				521
M60										
Depth of Excavation						8				
Area (SF)/Excavation cell						400			16	
Number of Cells to be Excavated						1				
Cubic Feet/Excavation cell	0	0	0	0	0	3200				
Cubic Yards/Excavation cell	0	0	0	0	0	119				
Tons/Excavation cell	0	0	0	0	0	190				
Total CY	0	0	0	0	0	119				119
Total Tons	0	0	0	0	0	190				190
Red Dot E of E140										
Depth of Excavation			3							
Area (SF)/Excavation cell			100						4	
Number of Cells to be Excavated			1							
Cubic Feet/Excavation cell	0	0	300	0	0	0				
Cubic Yards/Excavation cell	0	0	11	0	0	0				
Tons/Excavation cell	0	0	18	0	0	0				
Total CY	0	0	11	0	0	0				11
Total Tons	0	0	18	0	0	0				18

**Low Occupancy Future Use Scenario
Removal of PCBs > 50 ppm
Corrective Measures Study
Former Ciba-Geigy Facility
Cranston, RI**

Table B-1A Excavation of > 50 ppm PCBs

Area of Property	Interval								# Confirmation Samples	Soil to be Disposed
	0-1'	0-2'	0-3'	0-4'	0-6'	0-8'	2-4'	4-6'		
VOC Source Area (E280/E300)										
Depth of Excavation							2	2		
Area (SF)/Excavation cell							400	400	32	
Number of Cells to be Excavated							1	1		
Cubic Feet/Excavation cell	0	0	0	0	0	0	400	400		
Cubic Yards/Excavation cell	0	0	0	0	0	0	15	15		
Tons/Excavation cell	0	0	0	0	0	0	24	24		
Total CY	0	0	0	0	0	0	15	15		30
Total Tons	0	0	0	0	0	0	24	24		47
Total Confirmation Samples									304	
Total Area (SF)									7600	
Total CY										896
Total Tons										1434

Notes:

- i) All soil with greater than 50 ppm PCBs will be removed at any depth
- ii) The VOC soil source materials will be removed
- iii) Confirmation sampling is based on a 5 ft x 5 ft (subpart O) grid, which will be used for areas >50 ppm
- iv) Unit weight of 1.6 tons/CY is assumed
- v) VOC soil volume is not included in the total tonnage

Sequence of Work Anticipated to Include the Following:

- 1) First, excavation of all soil with PCBs > 50 ppm will occur; this soil will be disposed off-site (refer to Table 1)
- 2) The VOC source area will then be excavated and the soil will be disposed off-site (refer to Table 1)
- 3) Soil outside of the area to be capped that contains PCBs > 1 ppm in the top 2 ft will be excavated; this soil will be reused to restore the excavations from steps 1 and 2 (refer to Table 2)
- 4) An equivalent volume of backfill will be needed to restore the excavations from step 3 (refer to Table 2)
- 5) Soil will be brought in to create a 2 ft soil cap (refer to Table 3)

**Low Occupancy Future Use Scenario
Removal of PCBs > 50 ppm
Corrective Measures Study
Former Ciba-Geigy Facility
Cranston, RI**

Table B-1B Excavation of > 1 ppm PCBs in top two feet of soil outside area to be capped

Area of Property	Interval		# Confirmation Samples	Total Reusable Backfill
	0-1'	0-2'		
River Area				
Depth of Excavation		2		
Area (SF)/Excavation cell		400	96	
Number of Cells to be Excavated		24		
Cubic Feet/Excavation cell	0	800		
Cubic Yards/Excavation cell	0	30		
Tons/Excavation cell	0	47		
Total CY	0	711		711
Total Tons	0	1138		1138
SW Corner				
Depth of Excavation	1	2		
Area (SF)	400	400	40	
Number of Cells to be Excavated	9	1		
Cubic Feet/Excavation cell	400	800		
Cubic Yards/Excavation cell	15	30		
Tons/Excavation cell	24	47		
Total CY	133	30		163
Total Tons	213	47		261
E220				
Depth of Excavation		2		
Area (SF)		400	4	
Number of Cells to be Excavated		1		
Cubic Feet/Excavation cell	0	800		
Cubic Yards/Excavation cell	0	30		
Tons/Excavation cell	0	47		
Total CY	0	30		30
Total Tons	0	47		47
North Perimeter				
Depth of Excavation		2		
Area (SF)		400	16	
Number of Cells to be Excavated		4		
Cubic Feet/Excavation cell	0	800		
Cubic Yards/Excavation cell	0	30		
Tons/Excavation cell	0	47		
Total CY	0	119		119
Total Tons	0	190		190
Total Confirmation Samples			156	
Total Area			3900	
			Total CY	1022
			Total Tons	1636

Notes:

- i) Assumed soil removal above for reuse if it contains less than 25 ppm PCBs; other soil removed as part of the excavation.
- ii) Assumed no additional excavation required within flood plain beyond that in the River Area
- iii) Confirmation sampling is based on a 5 ft x 5 ft (subpart O) grid, which will be used for areas >50 ppm
- iv) Unit weight of 1.6 tons/CY is assumed

Sequence of Work Anticipated to Include the Following:

- 1) First, excavation of all soil with PCBs > 50 ppm will occur; this soil will be disposed off-site (refer to Table 1)
- 2) The VOC source area will then be excavated and the soil will be disposed of (refer to Table 1)
- 3) Soil outside of the area to be capped that contains PCBs > 1 ppm in the top 2 ft will be excavated; this soil will be reused to restore the excavations from steps 1 and 2 (refer to Table 2)
- 4) An equivalent volume of backfill will be needed to restore the excavations from step 3 (refer to Table 2)
- 5) Soil will be brought in to create a 2 ft soil cap (refer to Table 3)

**Low Occupancy Future Use Scenario
Removal of PCBs > 50 ppm
Corrective Measures Study
Former Ciba-Geigy Facility
Cranston, RI**

Table B-1C Volume for Soil Cap

Area of Property	Interval Capped
	0-2'
Cap	
Depth of Cap	2
Area (SF)/Excavation cell	400
Number of Cells to be Capped	150
Cubic Feet/Excavation cell	800
Cubic Yards/Excavation cell	30
Tons/Excavation cell	47
Total CY	4444
Total Tons	7111

Notes:

- i) Use central area of the site to consolidate excavated soil not needed for backfill in remedial excavations
- ii) Hold elevation at 100-year flood plains
- iii) Two feet of fill (less than 1 ppm PCBs) to serve as a cap over the consolidate and cap area
- iv) Two foot cap selection is based upon Rhode Island's regulations and anticipated ease to obtain regulatory approval
- v) Less than 1 ppm PCBs selected to comply with 761.61(a)(7)
- vi) Will inquire about variance from permeability and grading requirements
- vii) Unit weight of 1.6 tons/CY is assumed

Sequence of Work Anticipated to Include the Following:

- 1) First, excavation of all soil with PCBs > 50 ppm will occur; this soil will be disposed off-site (refer to Table 1)
- 2) The VOC source area will then be excavated and the soil will be disposed off-site (refer to Table 1)
- 3) Soil outside of the area to be capped that contains PCBs > 1 ppm in the top 2 ft will be excavated and this soil will be reused to restore the excavations from steps 1 and 2 (refer to Table 2)
- 4) An equivalent volume of backfill will be needed to restore the excavations from step 3 (refer to Table 2)
- 5) Soil will be brought in to create a 2 ft soil cap (refer to Table 3)

**High Occupancy Re-Use Option
Removal of PCBs > 10 ppm
Corrective Measures Study
Former Ciba-Geigy Facility
Cranston, RI**

Table B-2A Excavation of > 50 ppm PCBs

Area of Property	Interval								# Confirmation Samples	Reusable Backfill	Soil to be Disposed
	0-1'	0-2'	0-3'	0-4'	0-6'	0-8'	2-4'	4-6'			
3 Red Dots North of A300											
Depth of Excavation	1										
Area (SF)/Excavation cell	400								16		
Number of Cells to be Excavated	1										
Cubic Feet/Excavation cell	400	0	0	0	0	0					
Cubic Yards/Excavation cell	15	0	0	0	0	0					
Tons/Excavation cell	24	0	0	0	0	0					
Total CY	15	0	0	0	0	0					15
Total Tons	24	0	0	0	0	0					24
E280											
Depth of Excavation		2									
Area (SF)/Excavation cell		400							16		
Number of Cells to be Excavated		1									
Cubic Feet/Excavation cell	0	800	0	0	0	0					
Cubic Yards/Excavation cell	0	30	0	0	0	0					
Tons/Excavation cell	0	47	0	0	0	0					
Total CY	0	30	0	0	0	0					30
Total Tons	0	47	0	0	0	0					47
D220											
Depth of Excavation					6					1.5	
Area (SF)/Excavation cell					400				16	400	
Number of Cells to be Excavated					1					1	
Cubic Feet/Excavation cell	0	0	0	0	2400	0				600	
Cubic Yards/Excavation cell	0	0	0	0	89	0				22	
Tons/Excavation cell	0	0	0	0	142	0				36	
Total CY	0	0	0	0	89	0				22	67
Total Tons	0	0	0	0	142	0				36	107
B20											
Depth of Excavation	1										
Area (SF)/Excavation cell	400								16		
Number of Cells to be Excavated	1										
Cubic Feet/Excavation cell	400	0	0	0	0	0					
Cubic Yards/Excavation cell	15	0	0	0	0	0					
Tons/Excavation cell	24	0	0	0	0	0					
Total CY	15	0	0	0	0	0					15
Total Tons	24	0	0	0	0	0					24
Red Dot SE of D100											
Depth of Excavation	1										
Area (SF)/Excavation cell	100								4		
Number of Cells to be Excavated	1										
Cubic Feet/Excavation cell	100	0	0	0	0	0					
Cubic Yards/Excavation cell	4	0	0	0	0	0					
Tons/Excavation cell	6	0	0	0	0	0					
Total CY	4	0	0	0	0	0					4
Total Tons	6	0	0	0	0	0					6
Red/Orange Dot NE of D120											
Depth of Excavation	1										
Area (SF)/Excavation cell	100								4		
Number of Cells to be Excavated	1										
Cubic Feet/Excavation cell	100	0	0	0	0	0					
Cubic Yards/Excavation cell	4	0	0	0	0	0					
Tons/Excavation cell	6	0	0	0	0	0					
Total CY	4	0	0	0	0	0					4
Total Tons	6	0	0	0	0	0					6

High Occupancy Re-Use Option
Removal of PCBs > 10 ppm
Corrective Measures Study
Former Ciba-Geigy Facility
Cranston, RI

Table B-2A Excavation of > 50 ppm PCBs

Area of Property	Interval								# Confirmation Samples	Reusable Backfill	Soil to be Disposed
	0-1'	0-2'	0-3'	0-4'	0-6'	0-8'	2-4'	4-6'			
E160/E180/E200/F180											
Depth of Excavation		2									
Area (SF)/Excavation cell		400							64		
Number of Cells to be Excavated		4									
Cubic Feet/Excavation cell	0	800	0	0	0	0					
Cubic Yards/Excavation cell	0	30	0	0	0	0					
Tons/Excavation cell	0	47	0	0	0	0					
Total CY	0	119	0	0	0	0					119
Total Tons	0	190	0	0	0	0					190
Red Dot NE of E220											
Depth of Excavation	1										
Area (SF)/Excavation cell	100								4		
Number of Cells to be Excavated	1										
Cubic Feet/Excavation cell	100	0	0	0	0	0					
Cubic Yards/Excavation cell	4	0	0	0	0	0					
Tons/Excavation cell	6	0	0	0	0	0					
Total CY	4	0	0	0	0	0					4
Total Tons	6	0	0	0	0	0					6
Two Red Dots NE of E0											
Depth of Excavation	1										
Area (SF)/Excavation cell	300								12		
Number of Cells to be Excavated	1										
Cubic Feet/Excavation cell	300	0	0	0	0	0					
Cubic Yards/Excavation cell	11	0	0	0	0	0					
Tons/Excavation cell	18	0	0	0	0	0					
Total CY	11	0	0	0	0	0					11
Total Tons	18	0	0	0	0	0					18
Red Dot NE of G20											
Depth of Excavation	1										
Area (SF)/Excavation cell	100								4		
Number of Cells to be Excavated	1										
Cubic Feet/Excavation cell	100	0	0	0	0	0					
Cubic Yards/Excavation cell	4	0	0	0	0	0					
Tons/Excavation cell	6	0	0	0	0	0					
Total CY	4	0	0	0	0	0					4
Total Tons	6	0	0	0	0	0					6
J100											
Depth of Excavation		2									
Area (SF)/Excavation cell		400							16		
Number of Cells to be Excavated		1									
Cubic Feet/Excavation cell	0	800	0	0	0	0					
Cubic Yards/Excavation cell	0	30	0	0	0	0					
Tons/Excavation cell	0	47	0	0	0	0					
Total CY	0	30	0	0	0	0					30
Total Tons	0	47	0	0	0	0					47
I200											
Depth of Excavation						8					
Area (SF)/Excavation cell						400			16		
Number of Cells to be Excavated						1					
Cubic Feet/Excavation cell	0	0	0	0	0	3200					
Cubic Yards/Excavation cell	0	0	0	0	0	119					
Tons/Excavation cell	0	0	0	0	0	190					
Total CY	0	0	0	0	0	119					119
Total Tons	0	0	0	0	0	190					190

**High Occupancy Re-Use Option
Removal of PCBs > 10 ppm
Corrective Measures Study
Former Ciba-Geigy Facility
Cranston, RI**

Table B-2A Excavation of > 50 ppm PCBs

Area of Property	Interval								# Confirmation Samples	Reusable Backfill	Soil to be Disposed
	0-1'	0-2'	0-3'	0-4'	0-6'	0-8'	2-4'	4-6'			
H300/H280/G280/H260											
Depth of Excavation		2			6	8					
Area (SF)/Excavation cell		400			400	400			64		
Number of Cells to be Excavated		1			2	1					
Cubic Feet/Excavation cell	0	800	0	0	2400	3200					
Cubic Yards/Excavation cell	0	30	0	0	89	119					
Tons/Excavation cell	0	47	0	0	142	190					
Total CY	0	30	0	0	178	119					326
Total Tons	0	47	0	0	284	190					521
M60											
Depth of Excavation						8					
Area (SF)/Excavation cell						400			16		
Number of Cells to be Excavated						1					
Cubic Feet/Excavation cell	0	0	0	0	0	3200					
Cubic Yards/Excavation cell	0	0	0	0	0	119					
Tons/Excavation cell	0	0	0	0	0	190					
Total CY	0	0	0	0	0	119					119
Total Tons	0	0	0	0	0	190					190
Red Dot E of E140											
Depth of Excavation			3								
Area (SF)/Excavation cell			100						4		
Number of Cells to be Excavated			1								
Cubic Feet/Excavation cell	0	0	300	0	0	0					
Cubic Yards/Excavation cell	0	0	11	0	0	0					
Tons/Excavation cell	0	0	18	0	0	0					
Total CY	0	0	11	0	0	0					11
Total Tons	0	0	18	0	0	0					18
VOC Source Area (E280/E300)											
Depth of Excavation						2	2				
Area (SF)/Excavation cell						400	400		32		
Number of Cells to be Excavated						1	1				
Cubic Feet/Excavation cell	0	0	0	0	0	0	400	400			
Cubic Yards/Excavation cell	0	0	0	0	0	0	15	15			
Tons/Excavation cell	0	0	0	0	0	0	24	24			
Total CY	0	0	0	0	0	0	15	15			30
Total Tons	0	0	0	0	0	0	24	24			47
Total Confirmation Samples									304		
Total Area									7600		
Total CY										22	874
Total Tons										36	1399

Notes:

- i) All soil with greater than 50 ppm PCBs will be removed at any depth
- ii) The VOC soil source materials will be removed
- iii) The reusable backfill has less than 10 ppm PCBs
- iv) Confirmation sampling is based on a 5 ft x 5 ft (subpart O) grid, which will be used for areas >50 ppm
- v) Unit weight of 1.6 tons/CY is assumed
- vi) VOC soil volume is not included in the total tonnage

Sequence of Work Anticipated to Include the Following:

- 1) Excavate all soil that contains greater than 50 ppm PCBs; dispose off-site (refer to Table 1)
- 2) Excavate and stockpile top 1.5 ft of historic clean backfill (refer to Table 1)
- 3) Remove the VOC source area; dispose soil off-site (refer to Table 1)
- 4) Remove all soil with greater than 10 ppm PCBs (refer to Table 2)
- 5) Excavate and stockpile top 1.5 ft of historic clean backfill (refer to Table 2)
- 6) Remove all soil with greater than 1 ppm PCBs within the top 2 ft of soil and reuse at depths greater than 2 ft (refer to Table 3)
- 7) Import clean backfill and restore excavations to pre-excavation grades (refer to Table 4)

**High Occupancy Re-Use Option
Removal of PCBs > 10 ppm
Corrective Measures Study
Former Ciba-Geigy Facility
Cranston, RI**

Table B-2B Excavation of > 10 ppm PCBs

Area of Property	Interval							# Confirmation Samples	Reusable Backfill	Soil to be Disposed
	0-1'	0-2'	0-3'	0-4'	0-6'	0-8'	2-4'	4-6'		
Q0										
Depth of Excavation						8				
Area (SF)/Excavation cell						400		4		
Number of Cells to be Excavated						1				
Cubic Feet/Excavation cell	0	0	0	0	0	3200				
Cubic Yards/Excavation cell	0	0	0	0	0	119				
Tons/Excavation cell	0	0	0	0	0	190				
Total CY	0	0	0	0	0	119				119
Total Tons	0	0	0	0	0	190				190
O20/P20/P40 Plus Two Yellow Dots										
Depth of Excavation		2			6					
Area (SF)/Excavation cell		400			400			12		
Number of Cells to be Excavated		2			1					
Cubic Feet/Excavation cell	0	800	0	0	2400	0				
Cubic Yards/Excavation cell	0	30	0	0	89	0				
Tons/Excavation cell	0	47	0	0	142	0				
Total CY	0	59	0	0	89	0				148
Total Tons	0	95	0	0	142	0				237
Yellow/Orange Dots Around B40										
Depth of Excavation		3								
Area (SF)/Excavation cell		400						4		
Number of Cells to be Excavated		1								
Cubic Feet/Excavation cell	0	1200	0	0	0	0				
Cubic Yards/Excavation cell	0	44	0	0	0	0				
Tons/Excavation cell	0	71	0	0	0	0				
Total CY	0	44	0	0	0	0				44
Total Tons	0	71	0	0	0	0				71
D20										
Depth of Excavation	1									
Area (SF)/Excavation cell	400							4		
Number of Cells to be Excavated	1									
Cubic Feet/Excavation cell	400	0	0	0	0	0				
Cubic Yards/Excavation cell	15	0	0	0	0	0				
Tons/Excavation cell	24	0	0	0	0	0				
Total CY	15	0	0	0	0	0				15
Total Tons	24	0	0	0	0	0				24
Yellow Dot Near E20										
Depth of Excavation			3							
Area (SF)/Excavation cell			100					1		
Number of Cells to be Excavated			1							
Cubic Feet/Excavation cell	0	0	300	0	0	0				
Cubic Yards/Excavation cell	0	0	11	0	0	0				
Tons/Excavation cell	0	0	18	0	0	0				
Total CY	0	0	11	0	0	0				11
Total Tons	0	0	18	0	0	0				18
Orange Dot NE of E40										
Depth of Excavation			3							
Area (SF)/Excavation cell			100					1		
Number of Cells to be Excavated			1							
Cubic Feet/Excavation cell	0	0	300	0	0	0				
Cubic Yards/Excavation cell	0	0	11	0	0	0				
Tons/Excavation cell	0	0	18	0	0	0				
Total CY	0	0	11	0	0	0				11
Total Tons	0	0	18	0	0	0				18

**High Occupancy Re-Use Option
Removal of PCBs > 10 ppm
Corrective Measures Study
Former Ciba-Geigy Facility
Cranston, RI**

Table B-2B Excavation of > 10 ppm PCBs

Area of Property	Interval							# Confirmation Samples	Reusable Backfill	Soil to be Disposed
	0-1'	0-2'	0-3'	0-4'	0-6'	0-8'	2-4'	4-6'		
G40 Plus Yellow Dot SE G60										
Depth of Excavation				4						
Area (SF)/Excavation cell				400					8	
Number of Cells to be Excavated				2						
Cubic Feet/Excavation cell	0	0	0	1600	0	0				
Cubic Yards/Excavation cell	0	0	0	59	0	0				
Tons/Excavation cell	0	0	0	95	0	0				
Total CY	0	0	0	119	0	0				119
Total Tons	0	0	0	190	0	0				190
H20 Plus Orange Dot at H40										
Depth of Excavation				4						
Area (SF)/Excavation cell				100					4	
Number of Cells to be Excavated				4						
Cubic Feet/Excavation cell	0	0	0	400	0	0				
Cubic Yards/Excavation cell	0	0	0	15	0	0				
Tons/Excavation cell	0	0	0	24	0	0				
Total CY	0	0	0	59	0	0				59
Total Tons	0	0	0	95	0	0				95
C60										
Depth of Excavation	1									
Area (SF)/Excavation cell	400								4	
Number of Cells to be Excavated	1									
Cubic Feet/Excavation cell	400	0	0	0	0	0				
Cubic Yards/Excavation cell	15	0	0	0	0	0				
Tons/Excavation cell	24	0	0	0	0	0				
Total CY	15	0	0	0	0	0				15
Total Tons	24	0	0	0	0	0				24
Orange Dot at D60										
Depth of Excavation			3							
Area (SF)/Excavation cell			100						1	
Number of Cells to be Excavated			1							
Cubic Feet/Excavation cell	0	0	300	0	0	0				
Cubic Yards/Excavation cell	0	0	11	0	0	0				
Tons/Excavation cell	0	0	18	0	0	0				
Total CY	0	0	11	0	0	0				11
Total Tons	0	0	18	0	0	0				18
C80/D80 Plus Yellow Dots at A80/B80										
Depth of Excavation			3							
Area (SF)/Excavation cell			400						28	
Number of Cells to be Excavated			7							
Cubic Feet/Excavation cell	0	0	1200	0	0	0				
Cubic Yards/Excavation cell	0	0	44	0	0	0				
Tons/Excavation cell	0	0	71	0	0	0				
Total CY	0	0	311	0	0	0				311
Total Tons	0	0	498	0	0	0				498
Yellow Dot E of E80										
Depth of Excavation			3							
Area (SF)/Excavation cell			100						1	
Number of Cells to be Excavated			1							
Cubic Feet/Excavation cell	0	0	300	0	0	0				
Cubic Yards/Excavation cell	0	0	11	0	0	0				
Tons/Excavation cell	0	0	18	0	0	0				
Total CY	0	0	11	0	0	0				11
Total Tons	0	0	18	0	0	0				18

**High Occupancy Re-Use Option
Removal of PCBs > 10 ppm
Corrective Measures Study
Former Ciba-Geigy Facility
Cranston, RI**

Table B-2B Excavation of > 10 ppm PCBs

Area of Property	Interval								# Confirmation Samples	Reusable Backfill	Soil to be Disposed
	0-1'	0-2'	0-3'	0-4'	0-6'	0-8'	2-4'	4-6'			
J80											
Depth of Excavation		2									
Area (SF)/Excavation cell		400							4		
Number of Cells to be Excavated		1									
Cubic Feet/Excavation cell	0	800	0	0	0	0					
Cubic Yards/Excavation cell	0	30	0	0	0	0					
Tons/Excavation cell	0	47	0	0	0	0					
Total CY	0	30	0	0	0	0					30
Total Tons	0	47	0	0	0	0					47
Yellow/Orange Dots at F100, G100, H100, Yellow Dot at G120											
Depth of Excavation				4							
Area (SF)/Excavation cell				400					48		
Number of Cells to be Excavated				12							
Cubic Feet/Excavation cell	0	0	0	1600	0	0					
Cubic Yards/Excavation cell	0	0	0	59	0	0					
Tons/Excavation cell	0	0	0	95	0	0					
Total CY	0	0	0	711	0	0					711
Total Tons	0	0	0	1138	0	0					1138
Orange Dot NE of A120											
Depth of Excavation			3								
Area (SF)/Excavation cell			100						1		
Number of Cells to be Excavated			1								
Cubic Feet/Excavation cell	0	0	300	0	0	0					
Cubic Yards/Excavation cell	0	0	11	0	0	0					
Tons/Excavation cell	0	0	18	0	0	0					
Total CY	0	0	11	0	0	0					11
Total Tons	0	0	18	0	0	0					18
Yellow Dots Around J140											
Depth of Excavation			3								
Area (SF)/Excavation cell			400						4		
Number of Cells to be Excavated			1								
Cubic Feet/Excavation cell	0	0	1200	0	0	0	0	0			
Cubic Yards/Excavation cell	0	0	44	0	0	0	0	0			
Tons/Excavation cell	0	0	71	0	0	0	0	0			
Total CY	0	0	44	0	0	0	0	0			44
Total Tons	0	0	71	0	0	0	0	0			71
Orange Dot NW of C140											
Depth of Excavation			3								
Area (SF)/Excavation cell			100						1		
Number of Cells to be Excavated			1								
Cubic Feet/Excavation cell	0	0	300	0	0	0					
Cubic Yards/Excavation cell	0	0	11	0	0	0					
Tons/Excavation cell	0	0	18	0	0	0					
Total CY	0	0	11	0	0	0					11
Total Tons	0	0	18	0	0	0					18
G140											
Depth of Excavation	1										
Area (SF)/Excavation cell	400								4		
Number of Cells to be Excavated	1										
Cubic Feet/Excavation cell	400	0	0	0	0	0					
Cubic Yards/Excavation cell	15	0	0	0	0	0					
Tons/Excavation cell	24	0	0	0	0	0					
Total CY	15	0	0	0	0	0					15
Total Tons	24	0	0	0	0	0					24

**High Occupancy Re-Use Option
Removal of PCBs > 10 ppm
Corrective Measures Study
Former Ciba-Geigy Facility
Cranston, RI**

Table B-2B Excavation of > 10 ppm PCBs

Area of Property	Interval							# Confirmation Samples	Reusable Backfill	Soil to be Disposed
	0-1'	0-2'	0-3'	0-4'	0-6'	0-8'	2-4'	4-6'		
Yellow/Orange Dots at A160/A180										
Depth of Excavation			3							
Area (SF)/Excavation cell			400						12	
Number of Cells to be Excavated			3							
Cubic Feet/Excavation cell	0	0	1200	0	0	0				
Cubic Yards/Excavation cell	0	0	44	0	0	0				
Tons/Excavation cell	0	0	71	0	0	0				
Total CY	0	0	133	0	0	0				133
Total Tons	0	0	213	0	0	0				213
C160										
Depth of Excavation			3							
Area (SF)/Excavation cell			100						1	
Number of Cells to be Excavated			1							
Cubic Feet/Excavation cell	0	0	300	0	0	0				
Cubic Yards/Excavation cell	0	0	11	0	0	0				
Tons/Excavation cell	0	0	18	0	0	0				
Total CY	0	0	11	0	0	0				11
Total Tons	0	0	18	0	0	0				18
F160 Plus Yellow Dot E										
Depth of Excavation			3							
Area (SF)/Excavation cell			400						4	
Number of Cells to be Excavated			1							
Cubic Feet/Excavation cell	0	0	1200	0	0	0				
Cubic Yards/Excavation cell	0	0	44	0	0	0				
Tons/Excavation cell	0	0	71	0	0	0				
Total CY	0	0	44	0	0	0				44
Total Tons	0	0	71	0	0	0				71
J160										
Depth of Excavation		2								
Area (SF)/Excavation cell		400							4	
Number of Cells to be Excavated		1								
Cubic Feet/Excavation cell	0	800	0	0	0	0				
Cubic Yards/Excavation cell	0	30	0	0	0	0				
Tons/Excavation cell	0	47	0	0	0	0				
Total CY	0	30	0	0	0	0				30
Total Tons	0	47	0	0	0	0				47
Perimeter Excavation										
Depth of Excavation				4						
Area (SF)/Excavation cell				400					68	
Number of Cells to be Excavated				17						
Cubic Feet/Excavation cell	0	0	0	1600	0	0				
Cubic Yards/Excavation cell	0	0	0	59	0	0				
Tons/Excavation cell	0	0	0	95	0	0				
Total CY	0	0	0	1007	0	0			178	829
Total Tons	0	0	0	1612	0	0			285	1327
J200/J220										
Depth of Excavation	1									
Area (SF)/Excavation cell	400								8	
Number of Cells to be Excavated	2									
Cubic Feet/Excavation cell	400	0	0	0	0	0				
Cubic Yards/Excavation cell	15	0	0	0	0	0				
Tons/Excavation cell	24	0	0	0	0	0				
Total CY	30	0	0	0	0	0				30
Total Tons	47	0	0	0	0	0				47

**High Occupancy Re-Use Option
Removal of PCBs > 10 ppm
Corrective Measures Study
Former Ciba-Geigy Facility
Cranston, RI**

Table B-2B Excavation of > 10 ppm PCBs

Area of Property	Interval							# Confirmation Samples	Reusable Backfill	Soil to be Disposed
	0-1'	0-2'	0-3'	0-4'	0-6'	0-8'	2-4'	4-6'		
Yellow Dot Near J280										
Depth of Excavation	1									
Area (SF)/Excavation cell	100							1		
Number of Cells to be Excavated	1									
Cubic Feet/Excavation cell	100	0	0	0	0	0				
Cubic Yards/Excavation cell	4	0	0	0	0	0				
Tons/Excavation cell	6	0	0	0	0	0				
Total CY	4	0	0	0	0	0				4
Total Tons	6	0	0	0	0	0				6
G260										
Depth of Excavation			3							
Area (SF)/Excavation cell			400					4		
Number of Cells to be Excavated			1							
Cubic Feet/Excavation cell	0	0	1200	0	0	0				
Cubic Yards/Excavation cell	0	0	44	0	0	0				
Tons/Excavation cell	0	0	71	0	0	0				
Total CY	0	0	44	0	0	0				44
Total Tons	0	0	71	0	0	0				71
G300										
Depth of Excavation				4						
Area (SF)/Excavation cell				400				4		
Number of Cells to be Excavated				1						
Cubic Feet/Excavation cell	0	0	0	1600	0	0				
Cubic Yards/Excavation cell	0	0	0	59	0	0				
Tons/Excavation cell	0	0	0	95	0	0				
Total CY	0	0	0	59	0	0				59
Total Tons	0	0	0	95	0	0				95
H340/H320										
Depth of Excavation			3							
Area (SF)/Excavation cell			400					8		
Number of Cells to be Excavated			2							
Cubic Feet/Excavation cell	0	0	1200	0	0	0				
Cubic Yards/Excavation cell	0	0	44	0	0	0				
Tons/Excavation cell	0	0	71	0	0	0				
Total CY	0	0	89	0	0	0				89
Total Tons	0	0	142	0	0	0				142
Central Excavation										
Depth of Excavation		2								
Area (SF)/Excavation cell		400						100		
Number of Cells to be Excavated		25								
Cubic Feet/Excavation cell	0	800	0	0	0	0				
Cubic Yards/Excavation cell	0	30	0	0	0	0				
Tons/Excavation cell	0	47	0	0	0	0				
Total CY	0	741	0	0	0	0				741
Total Tons	0	1185	0	0	0	0				1185
Total Confirmation Samples								348		
Total Area								34800		
Total CY								178	3711	
Total Tons								285	5931	

Notes:

- i) The reusable backfill has less than 10 ppm PCBs
- ii) Confirmation sampling is based on a 5 ft x 5 ft (subpart O) grid, which will be used for areas >50 ppm
- iii) Unit weight of 1.6 tons/CY is assumed

Sequence of Work Anticipated to Include the Following:

- 1) Excavate all soil that contains greater than 50 ppm PCBs; dispose off-site (refer to Table 1)
- 2) Excavate and stockpile top 1.5 ft of historic clean backfill (refer to Table 1)
- 3) Remove the VOC source area; dispose soil off-site (refer to Table 1)
- 4) Remove all soil with greater than 10 ppm PCBs (refer to Table 2)
- 5) Excavate and stockpile top 1.5 ft of historic clean backfill (refer to Table 2)
- 6) Remove all soil with greater than 1 ppm PCBs within the top 2 ft of soil and reuse at depths greater than 2 ft (refer to Table 3)
- 7) Import clean backfill and restore excavations to pre-excavation grades (refer to Table 4)

**High Occupancy Re-Use Option
Removal of PCBs > 10 ppm
Corrective Measures Study
Former Ciba-Geigy Facility
Cranston, RI**

Table B-2C Excavation of > 1 ppm PCBs in Top 2 feet of Soil Outside of > 10 ppm Excavations

Area of the Property	Interval		Total Area	Total Volume of Backfill to be Reused
	0-1'	0-2'		
SE Corner				
Depth of Excavation		2		
Area (SF)/Excavation cell		400	4800	
Number of Cells to be Excavated		12		
Cubic Feet/Excavation cell	0	800		
Cubic Yards/Excavation cell	0	30		
Tons/Excavation cell	0	47		
Total CY	0	356		356
Total Tons	0	569		569
SW Corner				
Depth of Excavation	1			
Area (SF)/Excavation cell	400		3600	
Number of Cells to be Excavated	9			
Cubic Feet/Excavation cell	400	0		
Cubic Yards/Excavation cell	15	0		
Tons/Excavation cell	24	0		
Total CY	133	0		133
Total Tons	213	0		213
NW Corner				
Depth of Excavation		2		
Area (SF)/Excavation cell		400	2400	
Number of Cells to be Excavated		6		
Cubic Feet/Excavation cell	0	800		
Cubic Yards/Excavation cell	0	30		
Tons/Excavation cell	0	47		
Total CY	0	178		178
Total Tons	0	284		284
North Perimeter				
Depth of Excavation		2		
Area (SF)/Excavation cell		400	9600	
Number of Cells to be Excavated		24		
Cubic Feet/Excavation cell	0	800		
Cubic Yards/Excavation cell	0	30		
Tons/Excavation cell	0	47		
Total CY	0	711		711
Total Tons	0	1138		1138
Central Area				
Depth of Excavation		2		
Area (SF)/Excavation cell		400	12000	
Number of Cells to be Excavated		30		
Cubic Feet/Excavation cell	0	800		
Cubic Yards/Excavation cell	0	30		
Tons/Excavation cell	0	47		
Total CY	0	889		889
Total Tons	0	1422		1422

**High Occupancy Re-Use Option
Removal of PCBs > 10 ppm
Corrective Measures Study
Former Ciba-Geigy Facility
Cranston, RI**

Table B-2C Excavation of > 1 ppm PCBs in Top 2 feet of Soil Outside of > 10 ppm Excavations

Area of the Property	Interval		Total Area	Total Volume of Backfill to be Reused
	0-1'	0-2'		
River Area				
Depth of Excavation		2		
Area (SF)/Excavation cell		400	5200	
Number of Cells to be Excavated		13		
Cubic Feet/Excavation cell	0	800		
Cubic Yards/Excavation cell	0	30		
Tons/Excavation cell	0	47		
Total CY	0	385		385
Total Tons	0	616		616
West Perimeter				
Depth of Excavation		2		
Area (SF)/Excavation cell		400	6400	
Number of Cells to be Excavated		16		
Cubic Feet/Excavation cell	0	800		
Cubic Yards/Excavation cell	0	30		
Tons/Excavation cell	0	47		
Total CY	0	474		474
Total Tons	0	759		759
Total Area			44000	
Total CY				3126
Total Tons				5001

Notes:

- i) This soil will be consolidated below 2 feet of clean soil
- ii) Unit weight of 1.6 tons/CY is assumed

Sequence of Work Anticipated to Include the Following:

- 1) Excavate all soil that contains greater than 50 ppm PCBs; dispose off-site (refer to Table 1)
- 2) Excavate and stockpile top 1.5 ft of historic clean backfill (refer to Table 1)
- 3) Remove the VOC source area; dispose soil off-site (refer to Table 1)
- 4) Remove all soil with greater than 10 ppm PCBs (refer to Table 2)
- 5) Excavate and stockpile top 1.5 ft of historic clean backfill (refer to Table 2)
- 6) Remove all soil with greater than 1 ppm PCBs within the top 2 ft of soil and reuse at depths greater than 2 ft (refer to Table 3)
- 7) Import clean backfill and restore excavations to pre-excavation grades (refer to Table 4)

**High Occupancy Re-Use Option
Removal of PCBs > 10 ppm
Corrective Measures Study
Former Ciba-Geigy Facility
Cranston, RI**

Table B-2D Volume for Two Foot Clean Soil Layer

Step	Total Soil Excavated (CY)	Surface Area Excavated (SF)	Volume Needed for Top 2 ft (CY)	Total Reusable Soil Excavated (CY)	Volume of Reusable Soil Needed for Below 2 ft (CY)
<i>Removal of > 50 ppm PCBs</i>	896	7600	563	22	333
<i>Removal of > 10 ppm PCBs</i>	3889	34800	2578	178	1311
<i>Removal of > 1 ppm PCBs</i>	3126	44000	3259	3126	0
Total			6400	3326	1644
Volume of Sand Required			4800		
Volume of Top Soil Required			1600		

Notes:

i) Unit weight of 1.6 tons/CY is assumed

Sequence of Work Anticipated to Include the Following:

- 1) Excavate all soil that contains greater than 50 ppm PCBs; dispose off-site (refer to Table 1)
- 2) Excavate and stockpile top 1.5 ft of historic clean backfill (refer to Table 1)
- 3) Remove the VOC source area; dispose soil off-site (refer to Table 1)
- 4) Remove all soil with greater than 10 ppm PCBs (refer to Table 2)
- 5) Excavate and stockpile top 1.5 ft of historic clean backfill (refer to Table 2)
- 6) Remove all soil with greater than 1 ppm PCBs within the top 2 ft of soil and reuse at depths greater than 2 ft (refer to Table 3)
- 7) Import clean backfill and restore excavations to pre-excavation grades (refer to Table 4)

Unrestricted Future Use Scenario
Removal of PCBs > 1 ppm
Corrective Measures Study
Former Ciba-Geigy Facility
Cranston, RI

Table B-3A Excavation of > 1 ppm PCBs

Area of the Property	Interval												# Confirmation Samples	Volume of Reusable Backfill	Volume to be Disposed
	0-1'	0-2'	0-4'	0-6'	0-8'	1-2'	1-3'	1-4'	1-8'	2-4'	2-6'	2-8'			
SE Corner															
Depth of Excavation			4							2		6		1.5	
Area (SF)/Excavation cell			400							400		400	60	400	
Number of Cells to be Excavated			1							12		2		10	
Cubic Feet/Excavation cell	0	0	1600	0	0	0	0	0	0	800	0	2400		600	
Cubic Yards/Excavation cell	0	0	59	0	0	0	0	0	0	30	0	89		22	
Tons/Excavation cell	0	0	95	0	0	0	0	0	0	47	0	142		36	
Total CY	0	0	59	0	0	0	0	0	0	356	0	178		222	370
Total Tons	0	0	95	0	0	0	0	0	0	569	0	284		356	593
SW Corner															
Depth of Excavation	1	2								2				1.5	
Area (SF)/Excavation cell	400	400								400			72	400	
Number of Cells to be Excavated	9	2								7				3	
Cubic Feet/Excavation cell	400	800	0	0	0	0	0	0	0	800	0	0		600	
Cubic Yards/Excavation cell	15	30	0	0	0	0	0	0	0	30	0	0		22	
Tons/Excavation cell	24	47	0	0	0	0	0	0	0	47	0	0		36	
Total CY	133	59	0	0	0	0	0	0	0	207	0	0		67	333
Total Tons	213	95	0	0	0	0	0	0	0	332	0	0		107	533
NW Corner															
Depth of Excavation		2													
Area (SF)/Excavation cell		400											24		
Number of Cells to be Excavated		6													
Cubic Feet/Excavation cell	0	800	0	0	0	0	0	0	0	0	0	0			
Cubic Yards/Excavation cell	0	30	0	0	0	0	0	0	0	0	0	0			
Tons/Excavation cell	0	47	0	0	0	0	0	0	0	0	0	0			
Total CY	0	178	0	0	0	0	0	0	0	0	0	0		0	178
Total Tons	0	284	0	0	0	0	0	0	0	0	0	0		0	284
North Perimeter															
Depth of Excavation	1	2													
Area (SF)/Excavation cell	400	400											160		
Number of Cells to be Excavated	6	34													
Cubic Feet/Excavation cell	400	800	0	0	0	0	0	0	0	0	0	0			
Cubic Yards/Excavation cell	15	30	0	0	0	0	0	0	0	0	0	0			
Tons/Excavation cell	24	47	0	0	0	0	0	0	0	0	0	0			
Total CY	89	1007	0	0	0	0	0	0	0	0	0	0		0	1096
Total Tons	142	1612	0	0	0	0	0	0	0	0	0	0		0	1754

Unrestricted Future Use Scenario
Removal of PCBs > 1 ppm
Corrective Measures Study
Former Ciba-Geigy Facility
Cranston, RI

Table B-3A Excavation of > 1 ppm PCBs

Area of the Property	Interval												# Confirmation Samples	Volume of Reusable Backfill	Volume to be Disposed
	0-1'	0-2'	0-4'	0-6'	0-8'	1-2'	1-3'	1-4'	1-8'	2-4'	2-6'	2-8'			
Central Area															
Depth of Excavation	1	2	4	6	8	1		3							
Area (SF)/Excavation cell	400	400	400	400	400	400		400					276		
Number of Cells to be Excavated	13	24	17	7	3	3		2							
Cubic Feet/Excavation cell	400	800	1600	2400	3200	400	0	1200	0	0	0	0			
Cubic Yards/Excavation cell	15	30	59	89	119	15	0	44	0	0	0	0			
Tons/Excavation cell	24	47	95	142	190	24	0	71	0	0	0	0			
Total CY	193	711	1007	622	356	44	0	89	0	0	0	0		0	3022
Total Tons	308	1138	1612	996	569	71	0	142	0	0	0	0		0	4836
River Area															
Depth of Excavation	1	2	4		8	1	2	3	7		4				
Area (SF)/Excavation cell	400	400	400		400	400	400	400	400		400		108		
Number of Cells to be Excavated	2	4	7		4	2	4	1	2		1				
Cubic Feet/Excavation cell	400	800	1600	0	3200	400	800	1200	2800	0	1600	0			
Cubic Yards/Excavation cell	15	30	59	0	119	15	30	44	104	0	59	0			
Tons/Excavation cell	24	47	95	0	190	24	47	71	166	0	95	0			
Total CY	30	119	415	0	474	30	119	44	207	0	59	0		0	1496
Total Tons	47	190	664	0	759	47	190	71	332	0	95	0		0	2394
West Perimeter															
Depth of Excavation	1	2	4	6	8					2	4	6		1.5	
Area (SF)/Excavation cell	400	400	400	400	400					400	400	400	144	400	
Number of Cells to be Excavated	2	5	1	4	1					18	2	3		26	
Cubic Feet/Excavation cell	400	800	1600	2400	3200	0	0	0	0	800	1600	2400		600	
Cubic Yards/Excavation cell	15	30	59	89	119	0	0	0	0	30	59	89		22	
Tons/Excavation cell	24	47	95	142	190	0	0	0	0	47	95	142		36	
Total CY	30	148	59	356	119	0	0	0	0	533	119	267		578	1052
Total Tons	47	237	95	569	190	0	0	0	0	853	190	427		924	1683
Total Confirmation Samples													1072		
Total Area													84400		
Total CY														867	7548
Total Tons														1387	12077

Notes:

- i) All soil with greater than 50 ppm PCBs will be removed at any depth
- ii) The VOC soil source materials will be removed and are included in the West Perimeter Section (E280 VOC source material is from 2 to 4 ft and the E300 VOC source material is from 4 to 6 ft)
- iii) Confirmation sampling is based on a 5 ft x 5 ft (subpart O) grid, which will be used for areas >50 ppm
- iv) Unit weight of 1.6 tons/CY is assumed

Sequence of Work Anticipated to Include the Following:

- 1) First, excavation of all soil with PCBs that are greater than 50 ppm and the VOC source area will occur; this soil will be disposed off-Site (refer to Table 1)
- 2) The top 1.5 ft of historic clean backfill will be excavated and stockpiled
- 3) All soil that contains PCBs greater than 1 ppm will be excavated
- 4) The stockpiled historic clean backfill will be reused to begin to restore excavations
- 5) Clean backfill will be imported to continue to restore excavations to pre-excavation grades

**Unrestricted Future Use Option
Removal of PCBs > 1 ppm
Corrective Measures Study
Former Ciba-Geigy Facility
Cranston, RI**

Table B-3B Volume of Clean Fill Required

Area	Total Soil Excavated (CY)	Total Reusable Soil Excavated (CY)	Volume of Clean Fill Required (CY)
<i>SE Corner</i>	593	222	370
<i>SW Corner</i>	400	67	333
<i>NW Corner</i>	178	0	178
<i>North Perimeter</i>	1096	0	1096
<i>Central Area</i>	3022	0	3022
<i>River Area</i>	1496	0	1496
<i>West Perimeter</i>	1630	578	1052
Total		867	7548

Sequence of Work Anticipated to Include the Following:

- 1) First, excavation of all soil with PCBs that are greater than 50 ppm and the VOC source area will occur; this soil will be disposed off-Site (refer to Table 1)
- 2) The top 1.5 ft of historic clean backfill will be excavated and stockpiled
- 3) All soil that contains PCBs greater than 1 ppm will be excavated
- 4) The stockpiled historic clean backfill will be reused to begin to restore excavations
- 5) Clean backfill will be imported to continue to restore excavations to pre-excavation grades

Appendix C

Soil Remedial Options - Cost Estimates/Assumptions

Project Name:	BASF	Revision No.:	5
Cost Estimate No.:		Date:	3/21/14
Client	BASF	Status:	Draft
Location	Cranston, RI	Author:	SW/LW
		Office:	CHELM
Project Element:	> 50 mg/kg PCB Soil Remediation for Production Area		Reviewed By:
Type of Estimate:	Feasibility/Conceptual		

Project Details

Project Location:
 Project Start Date:
 Project Duration:
 Type of Contract: Direct Owner
 Level of Accuracy: -30% to +50%
 Contingency: 20%

Scope Summary

Summarize scope of work and provide project specific details with reference to source

Removal of PCBs in soil above 50 mg/kg in the Production Area, a 2 ft soil cap above PCB concentrations >1 mg/kg remaining on-site, and institutional controls implemented. Goal is low-occupancy Site re-use.

Document Source:	Rev. Date:	Site Visit?
Document Source:	Rev. Date:	
Document Source:	Rev. Date:	

Cost Summary

Prime Contractor Costs	\$	758,331
Other Contracts & Purchases	\$	785,487
Oversight Costs	\$	751,680
Project Total Estimated Cost	\$	2,295,498

Notes:

- Note intended use and audience
- List major project assumptions
- Accuracy ranges are based on information provided in "Association for Advancement of Cost Engineering (AACE), International Cost Estimating Classifications, 18R-97"

Estimate Type	Accuracy Range
Preliminary	-50% to +100%
Feasibility/Conceptual	-30% to +50%
Engineering	
30%	-20% to +30%
60%	-15% to +20%
90%	-10% to +15%

4. Contingency values are based on information provided in "USEPA, Guide to Developing Cost Estimates, July 2000

Remediation Technology	Scope Contingency
Soil Excavation	15% to 55%
Groundwater Treatment (Multiple)	15% to 35%
On-site Incineration	15% to 35%
Extraction Wells	10% to 30%
Vertical Barriers	10% to 30%
Synthetic Cap	10% to 20%
Off-site Disposal	5% to 15%
Off-site Incineration	5% to 15%
Bulk Liquid Processing	5% to 15%
Clay Cap	5% to 10%
Surface Grading/Diking	5% to 10%
Revegetation	5% to 10%

- Values and costs are for informational purposes only. Values are not true costs because they represent a combination of fixed capital and quantity-proportional components

BASF
Cranston, RI



> 50 mg/kg PCB Soil Remediation for Production Area

By: JML Rev Date: 3/21/2014

On-Site Source Removal. Excavation PCBs >50 mg/kg (to 6 ft bgs) + Cap + Institutional Controls									
Prime Contractor Costs					0%	20%			
Task ID	Task Descr.	Unit	Quantity	Bare Cost	MU	Contingency	Total Cost	Unit Rate	%
1	Mobilization	LS	1	\$25,000	\$0	\$5,000	\$30,000	\$30,000	4%
2	Temporary Facilities and Controls	LS	1	\$148,750	\$0	\$29,750	\$178,500	\$178,500	24%
3	Fencing and Erosion/Stormwater Controls	LF	2,300	\$35,075	\$0	\$7,015	\$42,090	\$18	6%
4	Decon Pad	LS	1	\$50,250	\$0	\$10,050	\$60,300	\$60,300	8%
5	Pre-characterization Sampling	LS	1	\$10,000	\$0	\$2,000	\$12,000	\$12,000	2%
6	Excavation for >50 mg/kg removal	CY	1,170	\$25,930	\$0	\$5,186	\$31,116	\$27	4%
7	Excavation/ Soil Handling Soil <50mg/kg) - Maintaining Site I	CY	1,226	\$40,647	\$0	\$8,129	\$48,776	\$40	6%
8	Backfill	CY	1,404	\$19,630	\$0	\$3,926	\$23,556	\$17	3%
9	Confirmation Sampling	LS	1	\$38,640	\$0	\$7,728	\$46,368	\$46,368	6%
10	Capping (clean soil placement + compaction)	CY	5,352	\$220,003	\$0	\$44,001	\$264,004	\$49	35%
11	Dewatering/WWTP - 7 - 10 ft	LS	1	\$0	\$0	\$0	\$0	\$0	0%
12	Northern Property Soil Removal	CY	52	\$2,593	\$0	\$519	\$3,112	\$60	0%
13	Northern Area Backfill	CY	62	\$4,101	\$0	\$820	\$4,921	\$79	1%
14	Site Restoration	LS	1	\$11,324	\$0	\$2,265	\$13,588	\$13,588	2%
				\$631,942	\$0	\$126,388	\$758,331		100%
Other Contracts & Purchases					0%	20%			
Task ID	Task Descr.	Unit	Quantity	Bare Cost	MU	Contingency	Total Cost	Unit Rate	%
1	Waste Disposal	ton	1,955	\$654,573	\$0	\$130,915	\$785,487	\$402	100%
				\$654,573	\$0	\$130,915	\$785,487		100%
Oversight Costs					0%	20%			
Task ID	Task Descr.	Unit	Quantity	Bare Cost	MU	Contingency	Total Cost	Unit Rate	%
1	Air Monitoring and Health and Safety	weeks	1	\$72,000	\$0	\$14,400	\$86,400	\$86,400	11%
2	Deed Restriction (ELUR)	LS	1	\$15,000	\$0	\$3,000	\$18,000	\$18,000	2%
3	Permitting Design	LS	1	\$240,000	\$0	\$48,000	\$288,000	\$288,000	38%
4	Personnel	Man Hours	1,124	\$299,400	\$0	\$59,880	\$359,280	\$320	48%
				\$626,400	\$0	\$125,280	\$751,680		100%
Grand Total							\$2,295,498		

SCOPE:

Removal of PCBs in soil above 50 mg/kg in the Production Area, a 2-ft soil cap above >1 mg/kg PCB, <50 mg/kg PCB concentrations in soil, and institutional controls implemented. Goal is low-occupancy Site re-use.

NOTES:

- Costs provided are not net present value costs.
 - Costs assume that excavation is down to 6 ft bgs for concentrations in soil greater than 50 mg/kg.
 - The above budgetary estimates do not account for unforeseen site conditions or regulatory changes that may occur.
 - Assume that no further remediation of the Pawtuxet River is required, consistent with our investigation and remedial actions to date
 - Costs do NOT include removal or redevelopment of former production facility buildings, sub-surface facility features, foundations, or piping, sumps, etc. left in place
 - Costs assume 1872 tons of waste: hazardous; 84 tons of waste: non-hazardous.
 - Costs assume that no dewatering is required for the soil excavation where PCBs >50 mg/kg as max excavation depth is 6-feet.
- MU - Mark-up
LS - Lump Sum
CY - Cubic Yard

Project Name:	BASF	Revision No.:	5
Cost Estimate No.:		Date:	3/19/14
Client	BASF	Status:	Draft
Location	Cranston, RI	Author:	SW/LW
		Office:	CHELM
Project Element:	> 10 mg/kg PCB Soil Remediation for Production Area		Reviewed By:
Type of Estimate:	Feasibility/Conceptual		

Project Details

Project Location:
 Project Start Date:
 Project Duration:
 Type of Contract: Direct Owner
 Level of Accuracy: -30% to +50%
 Contingency: 20%

Scope Summary

Summarize scope of work and provide project specific details with reference to source

Removal of PCBs in soil above 10 mg/kg in the Production Area, a 2 ft soil cap above PCB concentrations >1 mg/kg remaining on-site, and institutional controls implemented. Goal is low-occupancy Site re-use.

Document Source:	Rev. Date:	Site Visit?
Document Source:	Rev. Date:	
Document Source:	Rev. Date:	

Cost Summary

Prime Contractor Costs	\$	1,380,383
Other Contracts & Purchases	\$	1,847,964
Oversight Costs	\$	751,680
Project Total Estimated Cost	\$	3,980,027

Notes:

- Note intended use and audience
- List major project assumptions
- Accuracy ranges are based on information provided in "Association for Advancement of Cost Engineering (AACE), International Cost Estimating Classifications, 18R-97"

Estimate Type	Accuracy Range
Preliminary	-50% to +100%
Feasibility/Conceptual	-30% to +50%
Engineering	
30%	-20% to +30%
60%	-15% to +20%
90%	-10% to +15%

4. Contingency values are based on information provided in "USEPA, Guide to Developing Cost Estimates, July 2000

Remediation Technology	Scope Contingency
Soil Excavation	15% to 55%
Groundwater Treatment (Multiple)	15% to 35%
On-site Incineration	15% to 35%
Extraction Wells	10% to 30%
Vertical Barriers	10% to 30%
Synthetic Cap	10% to 20%
Off-site Disposal	5% to 15%
Off-site Incineration	5% to 15%
Bulk Liquid Processing	5% to 15%
Clay Cap	5% to 10%
Surface Grading/Diking	5% to 10%
Revegetation	5% to 10%

- Values and costs are for informational purposes only. Values are not true costs because they represent a combination of fixed capital and quantity-proportional components

> 10 mg/kg PCB Soil Remediation for Production Area

By: JML Rev Date: 3/19/2014

On-Site Source Removal. Excavation PCBs >10 mg/kg + Cap PCBs >1 mg/kg + Institutional Control:								
Prime Contractor Costs				0%	20%			
Task ID	Task Descr.	Unit	Quantity	Bare Cost	MU	Contingency	Total Cost	Unit Rate
1	Mobilization	LS	1	\$85,000	\$0	\$17,000	\$102,000	\$102,000
2	Temporary Facilities and Controls	LS	1	\$245,600	\$0	\$49,120	\$294,720	\$294,720
3	Fencing and Erosion/Stormwater Controls	LF	2,300	\$35,075	\$0	\$7,015	\$42,090	\$18
4	Decon Pad	LS	1	\$50,250	\$0	\$10,050	\$60,300	\$60,300
5	Foundation Demolition	LS	1	\$71,880	\$0	\$14,376	\$86,256	\$86,256
6	Pre-characterization Sampling	LS	1	\$0	\$0	\$0	\$0	\$0
7	Excavation Sheetpile	SF	1,200	\$60,000	\$0	\$12,000	\$72,000	\$60
8	Excavation-Phase 1 >50 mg/kg soils	CY	1,170	\$25,930	\$0	\$5,186	\$31,116	\$27
9	Excavation-Phase 2 >10 mg/kg soils	CY	5,067	\$88,162	\$0	\$17,632	\$105,794	\$21
10	Excavation-Phase 3 <10mg/kg Soils for Consolidation	CY	3,756	\$67,418	\$0	\$13,484	\$80,902	\$22
11	Soil Handling (moving excavated soil <50mg/kg)	CY	4,016	\$48,192	\$0	\$9,638	\$57,830	\$14
12	Backfill For Phase 1 and Phase 2 areas	CY	7,485	\$162,672	\$0	\$32,534	\$195,206	\$26
13	Excavation Northern Areas	CY	52	\$2,593	\$0	\$519	\$3,112	\$60
14	Backfill Northern Areas	CY	62	\$4,101	\$0	\$820	\$4,921	\$79
15	Confirmation Sampling	Ea	782	\$54,768	\$0	\$10,954	\$65,722	\$84
16	Capping (clean soil placement + compaction over specific are	CY	1,520	\$73,355	\$0	\$14,671	\$88,026	\$58
17	Dewatering/WWTP - 7 - 10 ft	LS	1	\$64,000	\$0	\$12,800	\$76,800	\$76,800
18	Site Restoration	LS	1	\$11,324	\$0	\$2,265	\$13,588	\$13,588
				\$1,150,320	\$0	\$230,064	\$1,380,383	100%
Other Contracts & Purchases								
Task ID	Task Descr.	Unit	Quantity	Bare Cost	MU	Contingency	Total Cost	Unit Rate
1	Waste Disposal	ton	10,923	\$1,539,970	\$0	\$307,994	\$1,847,964	\$169
				\$1,539,970	\$0	\$307,994	\$1,847,964	100%
Oversight Costs								
Task ID	Task Descr.	Unit	Quantity	Bare Cost	MU	Contingency	Total Cost	Unit Rate
1	Air Monitoring and Health and Safety	weeks	1	\$72,000	\$0	\$14,400	\$86,400	\$86,400
2	Deed Restriction (ELUR)	LS	1	\$15,000	\$0	\$3,000	\$18,000	\$18,000
3	Permitting Design	LS	1	\$240,000	\$0	\$48,000	\$288,000	\$288,000
4	Personnel	Man Hours	1,124	\$299,400	\$0	\$59,880	\$359,280	\$320
				\$626,400	\$0	\$125,280	\$751,680	100%
Grand Total							\$3,980,027	

SCOPE:

Removal of PCBs in soil above 10 mg/kg in the Production Area, a 2-ft engineered cap above soils with >1 mg/kg PCB concentrations remaining, and institutional controls implemented. Goal is high-occupancy Site re-use.

NOTES:

- Costs provided are not net present value costs.
- Costs assume that excavation is down to 6 ft bgs for concentrations in soil greater than 50 mg/kg.
- The above budgetary estimates do not account for unforeseen site conditions or regulatory changes that may occur.
- Assume that no further remediation of the Pawtuxet River is required, consistent with our investigation and remedial actions to date
- Costs do NOT include removal or redevelopment of former production facility buildings, sub-surface facility features, foundations, or piping, sumps, etc. left in place
- Costs assume 2180 tons of waste: hazardous; 8740 tons of waste: non-hazardous, includes some concrete sub-surface structure removal.
- Costs assume that no dewatering is required for the soil excavation where PCBs >50 mg/kg as max excavation depth is 6-feet.

MU - Mark-up

LS - Lump Sum

CY - Cubic Yard

Project Name: BASF
Cost Estimate No.:
Client BASF
Location Cranston, RI

Project Element: > 1 mg/kg PCB Soil Remediation

Type of Estimate: Feasibility/Conceptual

Revision No.: 2
Date: 3/19/14
Status: Draft
Author: LW/JML
Office: CHELM
Reviewed By:

Project Details

Project Location: Cranston, RI
Project Start Date:
Project Duration: 5 Mos
Type of Contract: Direct Owner
Level of Accuracy: -30% to +50%
Contingency: 20%

Scope Summary

Summarize scope of work and provide project specific details with reference to source

Removal of PCBs in soil above 1 mg/kg in the Production Area, as well as related building foundations and piping below ground surface (to 7 ft bgs), goal of unrestricted Site re-use.

Document Source: _____ **Rev. Date:** _____ **Site Visit?** _____
Document Source: _____ **Rev. Date:** _____
Document Source: _____ **Rev. Date:** _____

Cost Summary

Prime Contractor Costs \$ 3,250,993
Other Contracts & Purchases \$ 2,343,298
Oversight Costs \$ 803,520

Project Total Estimated Cost \$ 6,397,811

Notes:

- Note intended use and audience
- List major project assumptions
- Accuracy ranges are based on information provided in "Association for Advancement of Cost Engineering (AACE), International Cost Estimating Classifications, 18R-97"

Estimate Type	Accuracy Range
Preliminary	-50% to +100%
Feasibility/Conceptual	-30% to +50%
Engineering	
30%	-20% to +30%
60%	-15% to +20%
90%	-10% to +15%

- Contingency values are based on information provided in "USEPA, Guide to Developing Cost Estimates, July 2000"

Remediation Technology	Scope Contingency
Soil Excavation	15% to 55%
Groundwater Treatment (Multiple)	15% to 35%
On-site Incineration	15% to 35%
Extraction Wells	10% to 30%
Vertical Barriers	10% to 30%
Synthetic Cap	10% to 20%
Off-site Disposal	5% to 15%
Off-site Incineration	5% to 15%
Bulk Liquid Processing	5% to 15%
Clay Cap	5% to 10%
Surface Grading/Diking	5% to 10%
Revegetation	5% to 10%

- Values and costs are for informational purposes only. Values are not true costs because they represent a combination of fixed capital and quantity-proportional components. Costs provided are not net-present value costs.

BASF
Cranston, RI



> 1 mg/kg PCB Soil Remediation

By: LW/JML Rev Date: 3/19/2014

On-Site Source Removal. Excavation PCBs >1 mg/kg (to 7 ft bgs)									
Prime Contractor Costs									
Task ID	Task Descr.	Unit	Quantity	Bare Cost	0% MU	20% Contingency	Total Cost	Unit Rate	%
1	Mobilization	LS	1	\$85,000	\$0	\$17,000	\$102,000	\$102,000	3%
2	Temporary Facilities and Controls	MO	5	\$313,250	\$0	\$62,650	\$375,900	\$75,180	12%
3	Fencing and Erosion/Stormwater Controls	LF	2,300	\$35,075	\$0	\$7,015	\$42,090	\$18	1%
4	Excavation Dewatering	MO	5	\$50,000	\$0	\$10,000	\$60,000	\$12,000	2%
5	Decon Pad/Stockpile Area	LS	1	\$50,250	\$0	\$10,050	\$60,300	\$60,300	2%
6	Pre-characterization Sampling	Ea	13	\$15,600	\$0	\$3,120	\$18,720	\$1,440	1%
7	Excavation Sheetpile	SF	17,200	\$860,000	\$0	\$172,000	\$1,032,000	\$60	32%
8	Excavation	CY	10,940	\$186,696	\$0	\$37,339	\$224,035	\$20	7%
9	Backfill	CY	13,127	\$443,397	\$0	\$88,679	\$532,076	\$41	16%
10	Foundation Demolition, Removal and Disposal	Tons	1,230	\$103,720	\$0	\$20,744	\$124,464	\$101	4%
11	Confirmation Sampling	LS	1	\$90,048	\$0	\$18,010	\$108,058	\$108,058	3%
12	Dewatering/WWTP	LS	1	\$340,000	\$0	\$68,000	\$408,000	\$408,000	13%
13	Excavation Northern Areas	CY	189	\$2,593	\$0	\$519	\$3,112	\$17	0%
14	Backfill Northern Areas	CY	226	\$9,834	\$0	\$1,967	\$11,801	\$52	0%
15	Site Restoration	LS	1	\$123,698	\$0	\$24,740	\$148,437	\$148,437	5%
				\$2,709,161	\$0	\$541,832	\$3,250,993		100%
Other Contracts & Purchases									
Task ID	Task Descr.	Unit	Quantity	Bare Cost	0% MU	20% Contingency	Total Cost	Unit Rate	%
1	Waste Disposal	ton	16,739	\$1,952,748	\$0	\$390,550	\$2,343,298	\$140	100%
				\$1,952,748	\$0	\$390,550	\$2,343,298		100%
Oversight Costs									
Task ID	Task Descr.	Unit	Quantity	Bare Cost	0% MU	20% Contingency	Total Cost	Unit Rate	%
1	Air Monitoring and Health and Safety	weeks	1	\$96,000	\$0	\$19,200	\$115,200	\$115,200	14%
2	Deed Restriction	LS	-	\$0	\$0	\$0	\$0	#DIV/0!	0%
3	Permitting Design	LS	1	\$240,000	\$0	\$48,000	\$288,000	\$288,000	36%
4	Personnel	Man Hours	1,285	\$333,600	\$0	\$66,720	\$400,320	\$312	50%
				\$669,600	\$0	\$133,920	\$803,520		100%
Grand Total							\$6,397,811		

SCOPE:

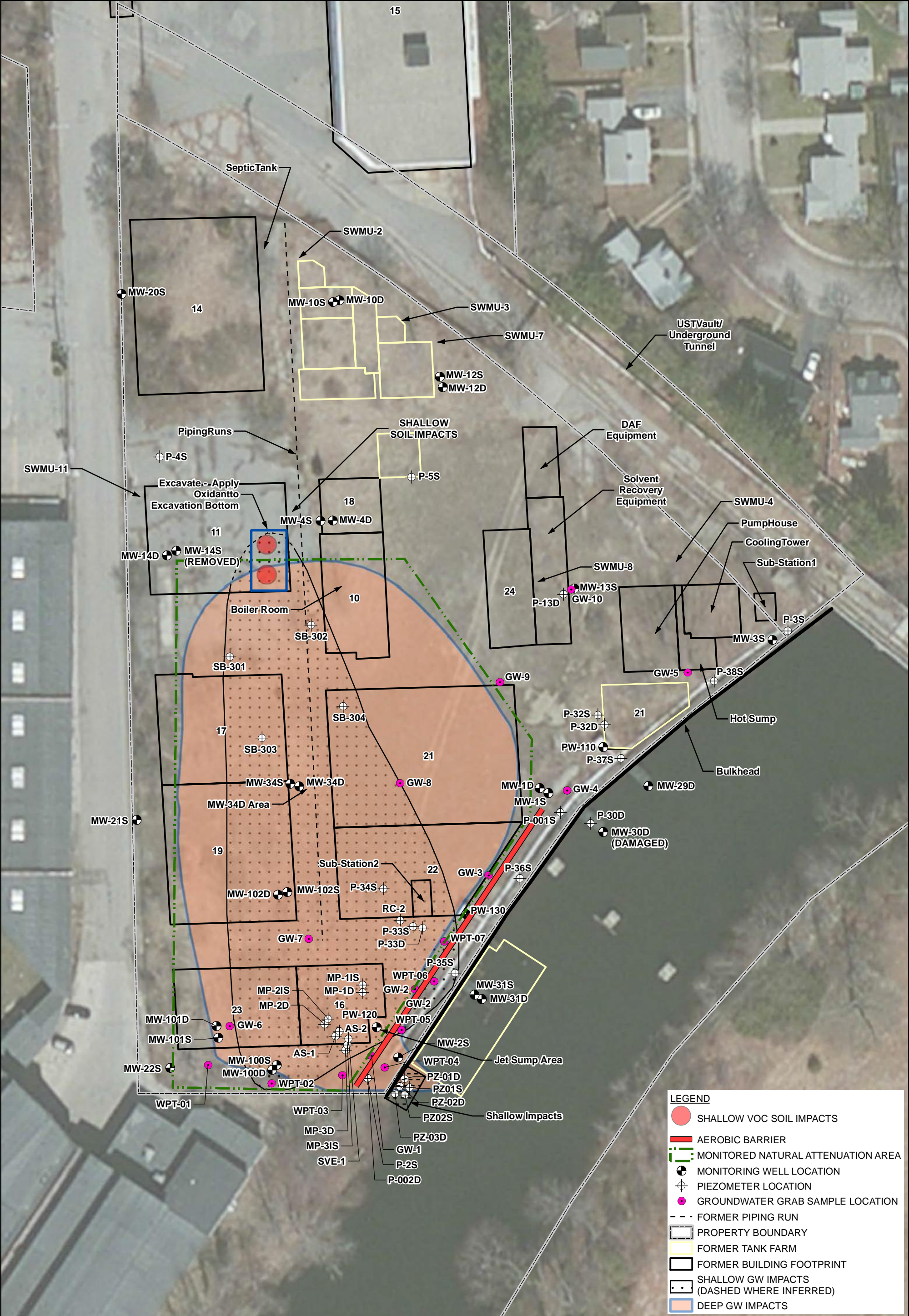
Removal of PCBs in soil above 1 mg/kg in the Production Area (to 7 ft bgs, including any building sub-surface structures that test positive for PCBs>1 mg/kg), and institutional controls implemented. Goal is unrestricted Site re-use.

NOTES:

- Costs provided are not net present value costs.
 - Costs assume that excavation is down to 8 ft bgs for concentrations in soil greater than 1 mg/kg. Sub-surface structures and piping below soil >1 mg/kg PCBs would be removed to 7 ft bgs, surfaces of the foundations outside these areas would be tested for PCB presence and sandblasted clean.
 - The above budgetary estimates do not account for unforeseen site conditions or regulatory changes that may occur.
 - Assume that no further remediation of the Pawtuxet River is required, consistent with our investigation and remedial actions to date
 - Costs do NOT include removal or redevelopment of former production facility buildings. Costs include removal of sub-surface facility features, foundations, or piping, sumps, etc. left in place that are below impacted soil, to 7 ft bgs.
 - Costs assume 15,000 tons of waste: <50mg/kg PCB's non-hazardous, 1,750 tons of waste >50 mg/kg PCB's hazardous.
 - Costs assume that limited dewatering is required for the soil excavation where PCBs >1 mg/kg.
- MU - Mark-up
LS - Lump Sum
CY - Cubic Yard

Appendix D

Groundwater Remedial Options - Conceptual Design Figures



Appendix E

Groundwater Remedial Options Cost Estimates/Assumptions

Project Name: BASF Production Area Groundwater
Cost Estimate No.: 1
Client: BASF
Location: Cranston, RI

Project Element: Environmental Land Use Restriction
Groundwater Corrective Measures Study
Type of Estimate: Feasibility/Conceptual

Revision No.: 1
Date: 2/27/14
Status: Final
Author: PG
Office: Rocky Hill
Reviewed By: LH
Date: 3/17/14
Revised: 8/31/2015



Project Details

Project Location: 180 Mill St, Cranston, RI
Project Start Date:
Project Duration:
Type of Contract: Direct Owner
Level of Accuracy: -30% to +50%
Contingency: 20%

Scope Summary

Summarize scope of work and provide project specific details with reference to source

Environmental Land Use Restriction consisting of deed restrictions prohibiting the use of groundwater indefinitely and groundwater monitoring.

Document Source: _____ **Rev. Date** _____ **Site Visit?** _____
Document Source: _____ **Rev. Date** _____
Document Source: _____ **Rev. Date** _____

Cost Summary

30 Year Projection
- 30% \$ 563,000
Total Cost Estimate \$ 804,000
+ 50% \$ 1,206,000

Notes:

1. Note intended use and audience
2. List major project assumptions
3. Accuracy ranges are based on information provided in "Association for Advancement of Cost Engineering (AACE), International Cost Estimating Classifications, 18R-97"

Estimate Type	Accuracy Range
Preliminary	-50% to +100%
Feasibility/Conceptual Engineering	-30% to +50%
30%	-20% to +30%
60%	-15% to +20%
90%	-10% to +15%

4. Values and costs are for informational purposes only. Values are not true costs because they represent a combination of fixed capital and quantity-proportional components

**BASF Production Area Groundwater
BASF
Cranston, RI
Environmental Land Use Restriction**



By: PG Rev Date: 3/17/2014

Capital Costs						
Task ID	Task Descr.	Unit	Quantity	Bare Cost	0% MU	20% Contingency
1	Project Planning and Reporting			\$50,000	\$0	\$10,000
2	Construction and Project Layout			\$3,564	\$0	\$713
Total Capital				\$53,564	\$0	\$10,713
Future Monitoring and O&M Costs						
Task ID	Task Descr.	Unit	Quantity	Bare Cost	0% MU	20% Contingency
1	Future Monitoring and O&M Costs			\$616,161	\$0	\$123,232
Total Cost						-30%
						\$563,000
						\$804,000
						+50%
						\$1,206,000

**BASF Production Area Groundwater
BASF
Cranston, RI
Environmental Land Use Restriction**



By: PG

Rev Date: 3/17/14

Task/Sub Task	Description	Unit	Qty	Rate	Mark-up	Total Cost	
Capital Costs							
1	Project Planning & Reporting					\$50,000	
	Prepare Documents and Plans including Permits	HR	150	\$100		\$15,000	
	Remedial Action Closeout Report	HR	100	\$100		\$10,000	
	Legal Support	LS	1	\$25,000		\$25,000	
2	Construction and Project Layout				8%	\$3,564	
	Land Use Control - As-Built	Days	2	\$1,650		\$3,564	
	SUB-TOTAL CAPITAL					\$53,564	\$53,564
	Contingency	20%					\$10,713
	Total Capital Costs						\$64,277
1	Future Monitoring and O&M Costs					\$616,161	
	SUB-TOTAL Future Costs					\$616,161	\$616,161
	Contingency	20%					\$123,232
	TOTAL FUTURE MONITORING AND O&M COSTS						\$739,394
						-30%	\$563,000
	Total Costs						\$804,000
						+50%	\$1,206,000

**BASF Production Area Groundwater
BASF
Cranston, RI
Environmental Land Use Restriction**



Present Value = $1/(1+DF)^n$		n	Multiplier	Discount factor	Annual Cost	PV of Cost
		0	1	1.0000	\$0	\$0
Discount Factor (DF)	2.5%	1	1	0.9756	\$62,900	\$61,366
		2	1	0.9518	\$62,900	\$59,869
Estimated Completion Time (Seasons)	30	3	1	0.9286	\$36,200	\$33,615
		4	1	0.9060	\$36,200	\$32,795
		5	1	0.8839	\$28,800	\$25,455
		6	1	0.8623	\$23,800	\$20,523
		7	1	0.8413	\$23,800	\$20,022
		8	1	0.8207	\$23,800	\$19,534
		9	1	0.8007	\$23,800	\$19,057
		10	1	0.7812	\$28,800	\$22,499
		11	1	0.7621	\$23,800	\$18,139
		12	1	0.7436	\$23,800	\$17,697
		13	1	0.7254	\$23,800	\$17,265
		14	1	0.7077	\$23,800	\$16,844
		15	1	0.6905	\$28,800	\$19,885
		16	1	0.6736	\$23,800	\$16,032
		17	1	0.6572	\$23,800	\$15,641
		18	1	0.6412	\$23,800	\$15,260
		19	1	0.6255	\$23,800	\$14,888
		20	1	0.6103	\$28,800	\$17,576
		21	1	0.5954	\$23,800	\$14,170
		22	1	0.5809	\$23,800	\$13,825
		23	1	0.5667	\$23,800	\$13,487
		24	1	0.5529	\$23,800	\$13,158
		25	1	0.5394	\$28,800	\$15,534
		26	1	0.5262	\$23,800	\$12,524
		27	1	0.5134	\$23,800	\$12,219
		28	1	0.5009	\$23,800	\$11,921
		29	1	0.4887	\$23,800	\$11,630
		30	1	0.4767	\$28,800	\$13,730
TOTAL PRESENT VALUE						\$616,161

**BASF Production Area Groundwater
BASF
Cranston, RI
Environmental Land Use Restriction**



ASSUMPTIONS

Performance Monitoring

Groundwater Performance Monitoring - Years 1-2 (Quarterly Sampling), Years 3-4 (Semi-Annual Sampling), and Years 5-30 (Annual Sampling).

ELUR

Assumes annual monitoring and 5 Year Review of ELUR will be incorporated into sitewide report.

Project Name: BASF Production Area Groundwater
Cost Estimate No.: 2
Client: BASF
Location: Cranston, RI

Project Element: Engineered Controls
Groundwater Corrective Measures Study
Type of Estimate: Feasibility/Conceptual

Revision No.: 1
Date: 3/12/14
Status: Final
Author: PG
Office: Rocky Hill
Reviewed By: LH
Date: 3/17/14
Revised: 8/31/2015



Project Details

Project Location: Mill St, Cranston, RI
Project Start Date:
Project Duration:
Type of Contract: Direct Owner
Level of Accuracy: -30% to +50%
Contingency: 20%

Scope Summary

Summarize scope of work and provide project specific details with reference to source

Incorporation of an engineered control(s) to mitigate plume migration to the river. Engineered Control approaches would consist of an impermeable engineered cap placed in the area of VOC vadose zone impacts and sheet piling would be installed downgradient just upgradient of the bulk head to prevent migration to the river.

Document Source: _____ **Rev. Date** _____ **Site Visit?** _____
Document Source: _____ **Rev. Date** _____
Document Source: _____ **Rev. Date** _____

Cost Summary

30 Year Projection
- 30% \$ 2,744,000
Total Cost Estimate \$ 3,919,658
+ 50% \$ 5,879,000

Notes:

- Note intended use and audience
- List major project assumptions
- Accuracy ranges are based on information provided in "Association for Advancement of Cost Engineering (AACE), International Cost Estimating Classifications, 18R-97"

Estimate Type	Accuracy Range
Preliminary	-50% to +100%
Feasibility/Conceptual Engineering	-30% to +50%
30%	-20% to +30%
60%	-15% to +20%
90%	-10% to +15%

- Values and costs are for informational purposes only. Values are not true costs because they represent a combination of fixed capital and quantity-proportional components

**BASF Production Area Groundwater
BASF
Cranston, RI
Engineered Controls**



By: PG

Rev Date:

3/17/2014

Capital Costs							
Task ID	Task Descr.	Unit	Quantity	Bare Cost	0% MU	20% Contingency	Total Cost
1	Permitting			\$32,400	\$0	\$6,480	\$38,880
2	Engineered Control Barrier (ECB) Construction			\$58,205	\$0	\$11,641	\$69,846
3	Waste Transportation and Disposal			\$135,040	\$0	\$27,008	\$162,048
4	Sheet Pile Installation			\$1,853,361	\$0	\$370,672	\$2,224,034
5	Engineering Oversight			\$623,702	\$0	\$124,740	\$748,442
TOTA CAPITAL COSTS							\$3,243,250
Remedial Costs (Year 1)							
Task ID	Task Descr.	Unit	Quantity	Bare Cost	0% MU	20% Contingency	Total Cost
1	Remedial Costs (Year 1)			\$20,290	\$0	\$4,058	\$24,348
TOTAL REMEDIAL COSTS (YEAR 1)							\$24,348
Future Monitoring and O&M Costs (Years 2-30)							
Task ID	Task Descr.	Unit	Quantity	Bare Cost	0% MU	20% Contingency	Total Cost
1	Future Costs			\$543,383	\$0	\$108,677	\$652,059
TOTAL FUTURE MONITORING AND O&M COSTS							\$652,059
- 30%							\$2,744,000
Total Cost							\$3,919,658
+ 50%							\$5,879,000

BASF Production Area Groundwater
BASF
Cranston, RI
Engineered Controls



Add Task

Delete Row

Add 1 Blank Row

By: PG

Rev Date: 3/17/14

Task/Sub Task	Description	Unit	Qty	Rate	Mark-up	Total Cost	
Capital Costs							
1	Permitting				8%	\$32,400	
	RIDEM Freshwater Wetlands Permit	LS	1	\$30,000		\$32,400	
2	Engineered Control Barrier (ECB) Construction				8%	\$58,205	
	40 mil HDPE Liner	SF	6,250	\$0.50		\$3,375	
	Geotextile Fabric	SF	6,250	\$0.17		\$1,125	
	Drainage Geocomposite	SF	6,250	\$0.70		\$4,725	
	Bedding Soil (6-inches)	CY	100	\$24		\$2,592	
	Vegetation Support Layer (12-inches)	CY	200	\$18		\$3,888	
	Topsoil (6-inches)	CY	100	\$31		\$3,348	
	Compactor	Day	4	\$68		\$294	
	Loader	Day	4	\$405		\$1,750	
	Excavator	Day	4	\$750		\$3,240	
	Skid Steer	Day	4	\$205		\$886	
	Operators (2)	Day	8	\$1,925		\$16,632	
	Laborers (2)	Day	8	\$1,580		\$13,651	
	Seeding	Acre	1.00	\$2,500		\$2,700	
3	Waste Transportation and Disposal				5.5%	\$135,040	
	TSCA PCBs>50 ppm	Ton	640	\$200.00		\$135,040	
4	Sheet Pile Installation				3%	\$1,853,361	
	Pre-Trenching	LS	1	\$25,000		\$25,750	
	Sheet Pile Material	lbs	1,223,000	\$0.70		\$881,783	
	Sheet Pile Install (ABI)	SF	52,200	\$15		\$806,490	
	Interlock Sealant	SF	52,200	\$2.40		\$129,038	
	Sheet Pile Design	LS	1	\$10,000		\$10,300	
5	Engineering Oversight					\$623,702	
SUB-TOTAL CAPITAL COSTS							\$2,702,709
Contingency 20%							\$540,542
TOTA CAPITAL COSTS							\$3,243,250
Remedial Costs (Year 1)							
1	Remedial Costs (Year 1)					\$20,290	
	Prepare IMM Work Plan	LS	1	\$6,232		\$6,232	
	Inspection and Maintenance (annual)	LS	1	\$3,040		\$3,040	
	Prepare Annual Report (for file)	LS	1	\$3,438		\$3,438	
	Establish Financial Surety	LS	1	\$7,580		\$7,580	
Sub-Total Remedial Costs (Year 1)							\$20,290
Contingency 20%							\$4,058
TOTAL REMEDIAL COSTS (YEAR 1)							\$24,348
Future Monitoring and O&M Costs (Years 2-30)							
1	Future Costs					\$543,383	
Sub-Total Future Costs							\$543,383
Contingency 20%							\$108,677
TOTAL FUTURE MONITORING AND O&M COSTS							\$652,059
Total Costs							\$2,744,000
							\$3,919,658
							\$5,879,000

**BASF Production Area Groundwater
BASF
Cranston, RI
Engineered Controls**



Present Value = $1/(1+DF)^n$		n	Multiplier	Discount factor	Annual Cost	PV of Cost
		0	1	1.0000	\$0	\$0
Discount Factor (DF)	2.5%	1	1	0.9756	\$0	\$0
		2	1	0.9518	\$68,678	\$65,369
Estimated Completion Time (Seasons)	30	3	1	0.9286	\$38,878	\$36,102
		4	1	0.9060	\$38,128	\$34,542
		5	1	0.8839	\$23,728	\$20,972
		6	1	0.8623	\$23,728	\$20,461
		7	1	0.8413	\$23,728	\$19,962
		8	1	0.8207	\$23,728	\$19,475
		9	1	0.8007	\$23,728	\$19,000
		10	1	0.7812	\$23,728	\$18,536
		11	1	0.7621	\$23,728	\$18,084
		12	1	0.7436	\$23,728	\$17,643
		13	1	0.7254	\$23,728	\$17,213
		14	1	0.7077	\$23,728	\$16,793
		15	1	0.6905	\$23,728	\$16,383
		16	1	0.6736	\$23,728	\$15,984
		17	1	0.6572	\$23,728	\$15,594
		18	1	0.6412	\$23,728	\$15,214
		19	1	0.6255	\$23,728	\$14,843
		20	1	0.6103	\$23,728	\$14,481
		21	1	0.5954	\$23,728	\$14,127
		22	1	0.5809	\$23,728	\$13,783
		23	1	0.5667	\$23,728	\$13,447
		24	1	0.5529	\$23,728	\$13,119
		25	1	0.5394	\$23,728	\$12,799
		26	1	0.5262	\$23,728	\$12,486
		27	1	0.5134	\$23,728	\$12,182
		28	1	0.5009	\$23,728	\$11,885
		29	1	0.4887	\$23,728	\$11,595
		30	1	0.4767	\$23,728	\$11,312
TOTAL PRESENT VALUE						\$543,383

**BASF Production Area Groundwater
BASF
Cranston, RI
Engineered Controls**



ASSUMPTIONS

Engineering Oversight

Assumes 30% of construction costs.

Performance Monitoring

Groundwater Performance Monitoring - Years 1-2 (Quarterly Sampling), Years 3-4 (Semi-Annual Sampling), and Years 5-30 (Annual Sampling)

Annual reporting included in future costs

Sheet Pile

Assumes pre-trenching will be required based on the potential of subsurface obstructions.

Assumes an installation depth of 60 feet into a dense till layer to act as a hydraulic cut-off layer preventing groundwater discharge to the river.

Assumes installation of AZ19-700 (23.41 lb/ft²).

Project Name: BASF Production Area Groundwater
Cost Estimate No.: 3
Client: BASF
Location: Cranston, RI

Project Element: Monitored Natural Attenuation
Groundwater Corrective Measures Study
Type of Estimate: Feasibility/Conceptual

Revision No.: 1
Date: 2/27/14
Status: Final
Author: PG
Office: Rocky Hill
Reviewed By: LH
Date: 3/17/14
Revised: 8/31/2015



Project Details

Project Location: Mill St, Cranston, RI
Project Start Date:
Project Duration:
Type of Contract: Direct Owner
Level of Accuracy: -30% to +50%
Contingency: 20%

Scope Summary

Summarize scope of work and provide project specific details with reference to source

Commence monitored natural attenuation until natural process have reduced concentrations of COCs to below applicable criteria. MNA groundwater will be conducted for an estimated 30 years.

Document Source: _____ **Rev. Date** _____ **Site Visit?** _____
Document Source: _____ **Rev. Date** _____
Document Source: _____ **Rev. Date** _____

Cost Summary

30 Year Projection
- 30% \$ 672,000
Total Cost Estimate \$ 959,425
+ 50% \$ 1,439,000

Notes:

- Note intended use and audience
- List major project assumptions
- Accuracy ranges are based on information provided in "Association for Advancement of Cost Engineering (AACE), International Cost Estimating Classifications, 18R-97"

Estimate Type	Accuracy Range
Preliminary	-50% to +100%
Feasibility/Conceptual Engineering	-30% to +50%
30%	-20% to +30%
60%	-15% to +20%
90%	-10% to +15%

- Values and costs are for informational purposes only. Values are not true costs because they represent a combination of fixed capital and quantity-proportional components

**BASF Production Area Groundwater
BASF
Cranston, RI
Monitored Natural Attenuation**



By: PG Rev Date: 3/17/2014

<i>Monitoring Costs (1-30 Years)</i>						
<i>Task ID</i>	<i>Task Descr.</i>	<i>Unit</i>	<i>Quantity</i>	<i>Bare Cost</i>	<i>0% MU</i>	<i>20% Contingency</i>
1	Groundwater Monitoring	LS	1	\$799,521	\$0	\$159,904
<i>Subtotal - Annual Expenses</i>						\$959,425
- 30%						\$672,000
<i>MNA - 30 Years (Present Value)</i>						\$959,425
+ 50%						\$1,439,000

BASF Production Area Groundwater
 BASF
 Cranston, RI
 Monitored Natural Attenuation



Add Task

Delete Row

Add 1 Blank Row

By: PG Rev Date: 3/17/14

Task/Sub Task	Description	Unit	Qty	Rate	Mark-up	Total Cost	
Monitoring Costs (1-30 Years)							
1	Groundwater Monitoring	LS	1	\$799,521		\$799,521	
SUB-TOTAL FUTURE MONITORING COSTS						\$799,521	\$799,521
Contingency 20%							\$159,904
TOTAL							\$959,425
- 30%							\$672,000
30 YEAR MNA COSTs - PRESENT VALUE							\$959,425
+ 50%							\$1,439,000

**BASF Production Area Groundwater
BASF
Cranston, RI
Monitored Natural Attenuation**



Present Value = $1/(1+DF)^n$		n	Multiplier	Discount factor	Annual Cost	PV of Cost
		0	1	1.0000	\$0	\$0
Discount Factor (DF)	2.5%	1	1	0.9756	\$94,500	\$92,195
		2	1	0.9518	\$94,500	\$89,946
Estimated Completion Time (Seasons)	30	3	1	0.9286	\$51,100	\$47,451
		4	1	0.9060	\$51,100	\$46,294
		5	1	0.8839	\$30,500	\$26,958
		6	1	0.8623	\$30,500	\$26,300
		7	1	0.8413	\$30,500	\$25,659
		8	1	0.8207	\$30,500	\$25,033
		9	1	0.8007	\$30,500	\$24,422
		10	1	0.7812	\$30,500	\$23,827
		11	1	0.7621	\$30,500	\$23,245
		12	1	0.7436	\$30,500	\$22,678
		13	1	0.7254	\$30,500	\$22,125
		14	1	0.7077	\$30,500	\$21,586
		15	1	0.6905	\$30,500	\$21,059
		16	1	0.6736	\$30,500	\$20,546
		17	1	0.6572	\$30,500	\$20,044
		18	1	0.6412	\$30,500	\$19,556
		19	1	0.6255	\$30,500	\$19,079
		20	1	0.6103	\$30,500	\$18,613
		21	1	0.5954	\$30,500	\$18,159
		22	1	0.5809	\$30,500	\$17,716
		23	1	0.5667	\$30,500	\$17,284
		24	1	0.5529	\$30,500	\$16,863
		25	1	0.5394	\$30,500	\$16,451
		26	1	0.5262	\$30,500	\$16,050
		27	1	0.5134	\$30,500	\$15,659
		28	1	0.5009	\$30,500	\$15,277
		29	1	0.4887	\$30,500	\$14,904
		30	1	0.4767	\$30,500	\$14,541
TOTAL PRESENT VALUE						\$799,521

**BASF Production Area Groundwater
BASF
Cranston, RI
Monitored Natural Attenuation**



ASSUMPTIONS

Performance Monitoring

Groundwater Performance Monitoring - Years 1-2 (Quarterly Sampling), Years 3-4 (Semi-Annual Sampling), and Years 5-30 (Annual Sampling).

Includes data evaluation and reporting for groundwater monitoring events.

Alternative 4: ISCO Barrier

Capital Costs

Task ID	Task Descr.	Unit	Quantity	Bare Cost	0% MU	20% Contingency	Total Cost
1	Pre-implementation	LS	1	\$17,564	\$0	\$3,513	\$21,077
2	Construction	LS	1	\$368,122	\$0	\$73,624	\$441,746
3	Residual Source Zone ISCO Treatment	LS	1	\$115,000	\$0	\$23,000	\$138,000
4	Engineering Oversight	LS	1	\$95,967	\$0	\$19,193	\$115,160
	Total Capital			\$596,653		\$119,331	\$715,983

Annual Operation & Maintenance Costs

Task ID	Task Descr.	Unit	Quantity	Bare Cost	0% MU	20% Contingency	Total Cost
1	Ozone System Operation, Maintenance & Monitoring	LS	1	\$154,440	\$0	\$30,888	\$185,328
2	Environmental Quality Performance Monitoring	LS	1	\$54,500	\$0	\$10,900	\$65,400
	Total Substrate and Performance Monitoring						\$250,728

Net Present Value of Annual O&M Costs

Task ID	Task Descr.	Unit	Quantity	Bare Cost	0% MU	20% Contingency	Total Cost
1	Ozone System Operation, Maintenance & Monitoring	LS	1	\$717,502	\$0	\$143,500	\$861,002
2	Environmental Quality Performance Monitoring	LS	1	\$616,618	\$0	\$123,324	\$739,941
	Total Future Monitoring and O&M Costs			\$1,334,119		\$266,824	\$1,600,943

NET PRESENT VALUE

Estimated Construction Costs		\$715,983
Net Present Value of Annual Costs for Years 1 - 30		\$1,600,943
	-30%	\$1,622,000
GRAND TOTAL	Estimated	\$2,317,000
	50%	\$3,476,000

Task/Subtask	Description	Unit	Qty	Rate	Mark-up	Total Cost
Capital Costs						
1	Pre-implementation				0%	\$17,564
	Design and Work Plan	LS	1	\$17,564	\$0	\$17,564
	Regulatory Approval/Permitting (RIDEM Freshwater Wetlands & GW Discharge)	ea		\$30,000	\$0	\$0
2	Construction				0%	\$368,122
	Groundwater monitoring well (shallow zone)	ea	6	\$4,000	\$0	\$24,000
	Groundwater monitoring well (deep zone)	ea	6	\$5,000	\$0	\$30,000
	Ozone sparge well using Sonic rig (shallow wells to 25 ft bgs)	ea	5	\$5,000	\$0	\$25,000
	Ozone sparge well using Sonic rig (deep wells to 46 ft bgs)	ea	13	\$6,000	\$0	\$78,000
	Ozone sparge piping and manifold	LS	200	\$410	\$0	\$82,000
	Ozone sparge system (either O3 and O2)	LS	1	\$85,000	\$0	\$85,000
	Electrical connection and power poles	LS	1	\$20,000	\$0	\$20,000
	Waste disposal	ea	49	\$150	\$0	\$7,280
	Well Permits	ea	18	\$519	\$0	\$9,342
	Discharge Permit	ea	1	\$7,500	\$0	\$7,500
3	Engineering Oversight				0%	\$95,967
	Construction Oversight and Startup Management	LS	1	\$52,692	\$0	\$52,692
		LS	1	\$43,275	\$0	\$43,275
Subtotal Capital Costs						\$481,653
	Contingency				20%	\$96,331
	TOTAL CAPITAL COSTS					\$577,983
Annual Operation & Maintenance						
1	Ozone System Operation, Maintenance & Monitoring				0.0%	\$154,440
	Ozone system maintenance (once every week; semi annual servicing, includes electricity, equipment replacement)	LS	1	\$87,800	\$0	\$87,800
	Groundwater Monitoring (quarterly)	ea	4	\$5,160	\$0	\$20,640
	Data evaluation and reporting (quarterly)	ea	4	\$6,500	\$0	\$26,000
	Project management (annual)	LS	1	\$20,000	\$0	\$20,000
2	Environmental Quality Performance Monitoring				0.0%	\$54,500
	Groundwater monitoring (QTY sampling and reporting)	LS	1	\$35,700	\$0	\$35,700
	ODCs - laboratory, equipment, travel, wastes	LS	1	\$18,800	\$0	\$18,800
Subtotal Annual Operation & Maintenance						\$208,940
	Contingency				20%	\$41,788
	TOTAL ANNUAL OPERATION & MAINTENANCE					\$250,728

Discount Factor 2.50%

Ozone System Operation, Maintenance & Monitoring

n	Multiplier	Discount factor	Annual Ozone System O&M	Annual Ozone System Performance GW Monitoring	Subtotal Annual Costs for Ozone System	PV of Annual Cost for Ozone System	GW Monitoring Program	PV of GW Monitoring Program	Total PV of Annual Costs
0	1	1.0000						\$0	\$0
1	1	0.9756	\$87,800	\$66,640	\$154,440	\$150,673	\$86,400	\$84,293	\$234,966
2	1	0.9518	\$87,800	\$66,640	\$154,440	\$146,998	\$86,400	\$82,237	\$229,235
3	1	0.9286	\$87,800	\$66,640	\$154,440	\$143,413	\$43,200	\$40,115	\$183,528
4	1	0.9060	\$87,800	\$66,640	\$154,440	\$139,915	\$43,200	\$39,137	\$179,052
5	1	0.8839	\$87,800	\$66,640	\$154,440	\$136,502	\$21,600	\$19,091	\$155,594
6	1	0.8623			\$0	\$0	\$21,600	\$18,626	\$18,626
7	1	0.8413			\$0	\$0	\$21,600	\$18,171	\$18,171
8	1	0.8207			\$0	\$0	\$21,600	\$17,728	\$17,728
9	1	0.8007			\$0	\$0	\$21,600	\$17,296	\$17,296
10	1	0.7812			\$0	\$0	\$21,600	\$16,874	\$16,874
11	1	0.7621			\$0	\$0	\$21,600	\$16,462	\$16,462
12	1	0.7436			\$0	\$0	\$21,600	\$16,061	\$16,061
13	1	0.7254			\$0	\$0	\$21,600	\$15,669	\$15,669
14	1	0.7077			\$0	\$0	\$21,600	\$15,287	\$15,287
15	1	0.6905			\$0	\$0	\$21,600	\$14,914	\$14,914
16	1	0.6736			\$0	\$0	\$21,600	\$14,550	\$14,550
17	1	0.6572			\$0	\$0	\$21,600	\$14,195	\$14,195
18	1	0.6412			\$0	\$0	\$21,600	\$13,849	\$13,849
19	1	0.6255			\$0	\$0	\$21,600	\$13,511	\$13,511
20	1	0.6103			\$0	\$0	\$21,600	\$13,182	\$13,182
21	1	0.5954			\$0	\$0	\$21,600	\$12,860	\$12,860
22	1	0.5809			\$0	\$0	\$21,600	\$12,547	\$12,547
23	1	0.5667			\$0	\$0	\$21,600	\$12,241	\$12,241
24	1	0.5529			\$0	\$0	\$21,600	\$11,942	\$11,942
25	1	0.5394			\$0	\$0	\$21,600	\$11,651	\$11,651
26	1	0.5262			\$0	\$0	\$21,600	\$11,367	\$11,367
27	1	0.5134			\$0	\$0	\$21,600	\$11,089	\$11,089
28	1	0.5009			\$0	\$0	\$21,600	\$10,819	\$10,819
29	1	0.4887			\$0	\$0	\$21,600	\$10,555	\$10,555
30	1	0.4767			\$0	\$0	\$21,600	\$10,298	\$10,298
			\$439,000	\$333,200	\$772,200	\$717,502	\$820,800	\$616,618	\$1,334,119

Project Name: BASF Production Area Groundwater
Cost Estimate No.: 8
Client BASF
Location Cranston, RI

Project Element: ISOC/O2 Barrier
 Groundwater Corrective Measures Study
Type of Estimate: Feasibility/Conceptual

Revision No.: 0
Date: 8/17/15
Status: Final
Author: MC
Office: Rocky Hill
Reviewed By: RDH
Date: 8/30/15



Project Details

Project Location: Mill St, Cranston, RI
Project Start Date:
Project Duration:
Type of Contract: Direct Owner
Level of Accuracy: -30% to +50%
Contingency: 20%

Scope Summary

Summarize scope of work and provide project specific details with reference to source

Construction of an ISOC barrier to saturate oxygen in groundwater for aerobic biodegradation of site COCs, along the southern-most portion of the Site, north of the bulk head wall. To be used in combination of a dig and haul of shallow soil at source, with an ISCO application

Document Source: _____ **Rev. Date** _____ **Site Visit?** _____
Document Source: _____ **Rev. Date** _____
Document Source: _____ **Rev. Date** _____

Cost Summary

30 Year Projection	
- 30% \$	972,000
Total Cost Estimate \$	1,388,000
+ 50% \$	2,082,000

Notes:

1. Note intended use and audience
2. List major project assumptions
3. Accuracy ranges are based on information provided in "Association for Advancement of Cost Engineering (AACE), International Cost Estimating Classifications, 18R-97"
4. Values and costs are for informational purposes only. Values are not true costs because they represent a combination of fixed capital and quantity-proportional components

BASF Production Area Groundwater
BASF
Cranston, RI
ISOC/O2 Barrier



By: MC Rev Date: 8/12/2015

Capital Costs							
Task ID	Task Descr.	Unit	Quantity	Bare Cost	0% MU	20% Contingency	Total Cost
1	Pre-implementation			\$206,000	\$0	\$41,200	\$247,200
2	ISOC Installation and Operations			\$176,257	\$0	\$35,251	\$211,508
3	Residual Source Area - ISCO			\$115,000	\$0	\$23,000	\$138,000
4	Construction			\$84,240	\$0	\$16,848	\$101,088
5	Engineering Oversight			\$87,072	\$0	\$17,414	\$104,486
Total Capital				\$668,569	\$0	\$133,714	\$802,282
Performance Monitoring, O&M (YEAR 1)							
Task ID	Task Descr.	Unit	Quantity	Bare Cost	0% MU	20% Contingency	Total Cost
1	Performance Monitoring - 1 year			\$86,400	\$0	\$17,280	\$103,680
Total Performance Monitoring, O&M (YEAR 1)				\$86,400	\$0	\$17,280	\$103,680
Future Monitoring, O&M (Years 2-30)							
Task ID	Task Descr.	Unit	Quantity	Bare Cost	0% MU	20% Contingency	Total Cost
1	Future Costs	0	-	\$517,057	\$0	\$103,411	\$620,468
Total Future Monitoring, O&M				\$517,057	\$0	\$103,411	\$620,468
Total Cost						-30%	\$972,000
						+50%	\$1,388,000
							\$2,082,000

BASF Production Area Groundwater
BASF
Cranston, RI
ISOC/O2 Barrier



By: MC

Rev Date: 8/12/15

Task/Sub Task	Description	Unit	Qty	Rate	Mark-up	Total Cost	
Capital Costs							
1	Pre-implementation				8.0%	\$206,000	
	Pilot Test and Pre-Design Investigation	ea	1	\$75,000		\$81,000	
	Design and Work Plan	ea	1	\$65,000		\$65,000	
	Regulatory Approval/Permitting (RIDEM Freshwater Wetlands & GW Discharge)	ea	2	\$30,000		\$60,000	
2	ISOC Installation and Operations				8.0%	\$176,257	
	Drilling for Well Installation (ADT)						
	Mobilization & Demobilization	LS	1	\$2,500		\$2,700	
	Truck Mount H.S.A Rig and Crew	per day	7	\$1,800		\$13,608	
	2" PVC Injection Wells Installed	per foot	420	\$15		\$6,804	
	12" Road Boxes (installed by others)	each	14	\$125		\$1,890	
	Engineering Procurement & Coordination	hours	60	\$135		\$8,748	
	Engineering Oversight Field	days	20	\$1,000		\$21,600	
	Engineering Oversight Office	hours	40	\$135		\$5,832	
	Project Management	hours	40	\$135		\$5,832	
	ISOC diffuser units	each	14	\$4,250		\$64,260	
	ISOC Accessories and Repair Kit	LS	1	\$500		\$540	
	Oxygen Regulators	each	2	\$108		\$233	
	Polyurethane tubing	linear feet	2100	\$0.55		\$1,247	
	ISOC Distribution Header (5 tank)	ea	2	\$425.00		\$918	
	Delivery and Shipping of ISOC Components	LS	1	\$1,000.00		\$1,080	
	Oxygen Cylinder Rental			10 cylinders for 60 months		\$6,180	
	Oxygen Cylinder Initial			Total 10 cylinders		\$580	
	Oxygen Cylinder Refills			Total 10 cylinders/quarterly fill for 5 yrs		\$11,938	
	Shipping Fee, Hazmat Fee, Fuel Surcharge Fee (Per Delivery)			Total for quarterly visits over 5 yrs		\$1,239	
	High Range DO Meter Rental	days	20	\$25.00		\$540	
	Chains and Misc Hardware	LS	1	\$250.00		\$270	
	Signage	LS	1	\$250.00		\$270	
	ISOC Enclosure and Connection to ISOC Wells (TMC)					\$0	
	Trailer/Seavan Included. Delivery & Setup	LS	1	\$5,800.00		\$6,264	
	Site Work	LS	1	\$10,000.00		\$10,800	
	Materials	LS	1	\$1,670.00		\$1,804	
	cylinder dolly	LS	1	\$1,000.00		\$1,080	
3	Construction				8%	\$84,240	
	Additional Monitoring Wells	ea	8	\$2,500		\$21,600	
	Preliminary Construction Costs (surveying, utility locating, site preparation etc.)	ea	1	\$50,000		\$54,000	
	Waste Characterization/Disposal from Soil Cuttings	ea	1	\$8,000		\$8,640	
4	Engineering Oversight					\$87,072	
SUB-TOTAL CAPITAL						\$553,569	\$553,569
Mark-up				3% Included in line items			
Contingency				20%			\$110,714
Total Capital Costs							\$664,282
Performance Monitoring, O&M (YEAR 1)							
1	Performance Monitoring - 1 year					\$86,400	
	Groundwater monitoring (QTY sampling and reporting), ISOC O+M					\$63,600	
	ODCs-laboratory, equipment, travel, wastes					\$22,800	
SUB-TOTAL PERFORMANCE MONITORING COSTS (YEAR 1)						\$86,400	\$86,400
Contingency				20%			\$17,280
Total Monitoring Costs (YEAR 1)							\$103,680
Future Monitoring, O&M (Years 2-30)							
1	Future Costs					\$517,057	
Sub-Total Future Costs (Years 2-30)						\$517,057	\$517,057
Contingency				20%			\$103,411
TOTAL FUTURE MONITORING, O&M AND RE-INJECTION COSTS							\$620,468
Total Costs						-30%	\$972,000
							\$1,388,000
						+50%	\$2,082,000

**BASF Production Area Groundwater
BASF
Cranston, RI
Aerobic Biodegradation**



Present Value = $1/(1+DF)^n$		n	Multiplier	Discount factor	Annual Cost	PV of Cost
		0	1	1.0000	\$0	\$0
Discount Factor (DF)	2.5%	1	1	0.9756	\$0	\$0
		2	1	0.9518	\$86,400	\$82,237
Estimated Completion Time (Seasons)	30	3	1	0.9286	\$43,300	\$40,208
		4	1	0.9060	\$43,300	\$39,228
		5	1	0.8839	\$20,700	\$18,296
		6	1	0.8623	\$20,700	\$17,850
		7	1	0.8413	\$20,700	\$17,414
		8	1	0.8207	\$20,700	\$16,989
		9	1	0.8007	\$20,700	\$16,575
		10	1	0.7812	\$20,700	\$16,171
		11	1	0.7621	\$20,700	\$15,776
		12	1	0.7436	\$20,700	\$15,392
		13	1	0.7254	\$20,700	\$15,016
		14	1	0.7077	\$20,700	\$14,650
		15	1	0.6905	\$20,700	\$14,293
		16	1	0.6736	\$20,700	\$13,944
		17	1	0.6572	\$20,700	\$13,604
		18	1	0.6412	\$20,700	\$13,272
		19	1	0.6255	\$20,700	\$12,948
		20	1	0.6103	\$20,700	\$12,633
		21	1	0.5954	\$20,700	\$12,324
		22	1	0.5809	\$20,700	\$12,024
		23	1	0.5667	\$20,700	\$11,731
		24	1	0.5529	\$20,700	\$11,445
		25	1	0.5394	\$20,700	\$11,165
		26	1	0.5262	\$20,700	\$10,893
		27	1	0.5134	\$20,700	\$10,627
		28	1	0.5009	\$20,700	\$10,368
		29	1	0.4887	\$20,700	\$10,115
		30	1	0.4767	\$20,700	\$9,869
TOTAL PRESENT VALUE						\$517,057

BASF Production Area Groundwater
BASF
Cranston, RI
ISOC/O2 Barrier



ASSUMPTIONS

Engineering Oversight

Assumes 30% of construction costs.

ISOC Well Installation

2" Wells Installed for ISOC Placement via Hollow Stem Auger	15	feet apart
O2 Barrier Length	200	feet
Treatment Interval - ISOC Units Set In 10 ft Screens	16-26	feet bgs
Number of ISOC units at 10 ft spacing	14	units

O2 Delivery and Performance

Oxygen injection will be continuous for 5 years	60 months
Oxygen tank changeout/refill will occur quarterly	
Water is not available for use at the site	

Performance Monitoring

Groundwater Performance Monitoring - Years 1-2 (Quarterly Sampling), Years 3-4 (Semi-Annual Sampling), and Years 5-30 (Annual Sampling)
O+M occurs quarterly for 5 years (labor added to monitoring costs), addition of 1 day/2 people
Data evaluation and reporting included in task

Permitting

RIDEM Freshwater Wetlands Permit - Assumes a Request for Preliminary Determination (PD) is used with a decision of "insignificant alteration" due to this area being located in a riverbank wetland.
RIDEM Groundwater Discharge Permit - Injection activities

Project Name: BASF Production Area Groundwater
Cost Estimate No.: 6
Client: BASF
Location: Cranston, RI

Project Element: P & T System Operation

Type of Estimate: Feasibility/Conceptual

Revision No.: 1
Date: 3/14/14
Status: Final
Author: PG
Office: Rocky Hill
Reviewed By: LH
Date: 3/17/14



Project Details

Project Location: Mill St, Cranston, RI
Project Start Date:
Project Duration:
Type of Contract: Direct Owner
Level of Accuracy: -30% to +50%
Contingency: 20%

Scope Summary

Summarize scope of work and provide project specific details with reference to source

Minimal repair and continued operation of current pump and treat groundwater remediation system includes maintaining current pumping rates and system configuration.

Document Source: _____ Rev. Date _____ Site Visit? _____
 Document Source: _____ Rev. Date _____
 Document Source: _____ Rev. Date _____

Cost Summary

30 Year Projection
 - 30% \$ 5,338,550
Total Cost Estimate \$ 7,626,500
 + 50% \$ 11,439,750

Notes:

1. Note intended use and audience
2. List major project assumptions
3. Accuracy ranges are based on information provided in "Association for Advancement of Cost Engineering (AACE), International Cost Estimating Classifications, 18R-97"

Estimate Type	Accuracy Range
Preliminary	-50% to +100%
Feasibility/Conceptual	-30% to +50%
Engineering	
30%	-20% to +30%
60%	-15% to +20%
90%	-10% to +15%

4. Values and costs are for informational purposes only. Values are not true costs because they represent a combination of fixed capital and quantity-proportional components

**BASF Production Area Groundwater
BASF
Cranston, RI
P & T System Operation**



By: PG Rev Date: 3/17/2014

Capital Costs							
Task ID	Task Descr.	Unit	Quantity	Bare Cost	0% MU	20% Contingency	Total Cost
1	Equipment	0	-	\$54,000	\$0	\$10,800	\$64,800
2	Materials	0	-	\$0	\$0	\$0	\$0
3	Engineering	0	-	\$0	\$0	\$0	\$0
4	Contractors	0	-	\$0	\$0	\$0	\$0
Total Capital Costs				\$54,000	\$0	\$10,800	\$64,800
Monitoring and O&M Costs (Year 1)							
Task ID	Task Descr.	Unit	Quantity	Bare Cost	0% MU	20% Contingency	Total Cost
1	Waste Management	0	-	\$54,000	\$0	\$10,800	\$64,800
2	System Repairs and Maintenance	0	-	\$56,700	\$0	\$11,340	\$68,040
3	Remedial System Operations	0	-	\$102,600	\$0	\$20,520	\$123,120
4	Effluent Monitoring and Reporting	0	-	\$15,000	\$0	\$3,000	\$18,000
5	Site Supervision	0	-	\$37,500	\$0	\$7,500	\$45,000
6	Groundwater Monitoring	0	-	\$42,000	\$0	\$8,400	\$50,400
Total Annual O&M Costs				\$307,800	\$0	\$61,560	\$369,360
Future Monitoring, O&M and System Upgrade/Repair Costs (Years 2-30)							
Task ID	Task Descr.	Unit	Quantity	Bare Cost	0% MU	20% Contingency	Total Cost
1	Future Costs	0	-	\$5,993,617	\$0	\$1,198,723	\$7,192,340
Total Future Costs				\$5,993,617	\$0	\$1,198,723	\$7,192,340
Total P&T and Monitoring Costs - 30 years (Present value)						-30%	\$5,338,550
						+50%	\$7,626,500
							\$11,439,750

**BASF Production Area Groundwater
BASF
Cranston, RI
P & T System Operation**



By: PG Rev Date: 3/17/14

Task/Sub Task	Description	Unit	Qty	Rate	Mark-up	Total Cost	
Capital Costs							
1	Equipment				8%	\$54,000	
	Repair and Set-up of Current P&T System	LS	1	\$50,000		\$54,000	
						\$0	
2	Materials					\$0	
						\$0	
						\$0	
3	Engineering					\$0	
						\$0	
						\$0	
4	Contractors					\$0	
						\$0	
						\$0	
SUB-TOTAL CAPITAL						\$54,000	\$54,000
Contingency						20%	\$10,800
Total Capital Costs							\$64,800
Monitoring and O&M Costs (Year 1)							
1	Waste Management				8%	\$54,000	
	Discharge Fee					\$54,000	
						\$0	
2	System Repairs and Maintenance				8%	\$56,700	
	Labor					\$29,700	
	Equipment & Materials					\$5,400	
	Subcontractors					\$16,200	
	Misc-Subcontractors					\$5,400	
3	Remedial System Operations				8%	\$102,600	
	Labor					\$54,000	
	Equipment & Materials					\$16,200	
	Utilities					\$27,000	
	Misc-Subcontractors					\$5,400	
4	Effluent Monitoring and Reporting					\$15,000	
	Subcontractors					\$15,000	
						\$0	
5	Site Supervision					\$37,500	
	Labor					\$37,500	
						\$0	
6	Groundwater Monitoring					\$42,000	
SUB-TOTAL ANNUAL O&M COSTS						\$307,800	\$307,800
Contingency						20%	\$61,560
Total Annual O&M Costs							\$369,360
Future Monitoring, O&M and System Upgrade/Repair Costs (Years 2-30)							
1	Future Costs					\$5,993,617	
Sub-Total Future Costs (Years 2-30)						\$5,993,617	\$5,993,617
Contingency						20%	\$1,198,723
TOTAL FUTURE MONITORING, O&M AND UPGRADE/REPAIR COSTS (YEARS 2-30)							\$7,192,340
Total P&T and Monitoring Costs - 30 years (Present value)						-30%	\$5,338,550
						+50%	\$11,439,750

**BASF Production Area Groundwater
BASF
Cranston, RI
P & T System Operation**



Present Value = $1/(1+DF)^n$		n	Multiplier	Discount factor	System Upgrades/ Repair	Annual Cost	PV of Cost
		0	1	1.0000		\$0	\$0
Discount Factor (DF)	2.5%	1	1	0.9756		\$0	\$0
		2	1	0.9518		\$318,200	\$302,867
Estimated Completion Time (Seasons)	30	3	1	0.9286		\$296,200	\$275,051
		4	1	0.9060		\$295,298	\$267,525
		5	1	0.8839		\$284,198	\$251,190
		6	1	0.8623		\$284,198	\$245,063
		7	1	0.8413		\$284,198	\$239,086
		8	1	0.8207		\$284,198	\$233,255
		9	1	0.8007		\$284,198	\$227,565
		10	1	0.7812	\$250,000	\$227,498	\$373,021
		11	1	0.7621		\$284,198	\$216,600
		12	1	0.7436		\$284,198	\$211,317
		13	1	0.7254		\$284,198	\$206,163
		14	1	0.7077		\$284,198	\$201,135
		15	1	0.6905		\$284,198	\$196,229
		16	1	0.6736		\$284,198	\$191,443
		17	1	0.6572		\$284,198	\$186,774
		18	1	0.6412		\$284,198	\$182,218
		19	1	0.6255		\$284,198	\$177,774
		20	1	0.6103	\$250,000	\$227,498	\$291,403
		21	1	0.5954		\$284,198	\$169,208
		22	1	0.5809		\$284,198	\$165,081
		23	1	0.5667		\$284,198	\$161,054
		24	1	0.5529		\$284,198	\$157,126
		25	1	0.5394		\$284,198	\$153,294
		26	1	0.5262		\$284,198	\$149,555
		27	1	0.5134		\$284,198	\$145,907
		28	1	0.5009		\$284,198	\$142,348
		29	1	0.4887		\$284,198	\$138,877
		30	1	0.4767		\$284,198	\$135,489
TOTAL PRESENT VALUE							\$5,993,617

Note: Annual costs consists of performance groundwater monitoring, waste management, system repairs & maintenance, effluent monitoring and reporting and site supervision.

**BASF Production Area Groundwater
BASF
Cranston, RI
P & T System Operation**



ASSUMPTIONS

Capital Costs

Assumed repair and set-up costs of the current groundwater pump and treat remediation system. Assumes \$1.00 per 1,000 gallons for the discharge fee with a discharge rate of 80 gpm.

Performance Monitoring

Groundwater Performance Monitoring - Years 1-2 (Quarterly Sampling), Years 3-4 (Semi-Annual Sampling), and Years 5-30 (Annual Sampling).

Conceptual Design Groundwater Pretreatment

The following reasonable and tenable assumptions were made for the conceptual design of the pretreatment system:

- The general types of constituents known to exist on-site (based on earlier studies and pilot testing) will not change.
- The pretreatment system will be located on the main floor of the former warehouse.
- Pretreated groundwater will be discharged to the Cranston POTW via the existing sanitary sewer on the property. No pretreated groundwater will be discharged to the Pawtuxet River or reinjected to the groundwater at this time. However, the pretreatment system will be designed so that discharge to these locations in the future is possible (if these alternatives are pursued) with minor modifications to the system.
- Vapor-phase activated carbon adsorption treatment will be provided on the air stripper discharge to reduce the potential for odors. After the activated carbon adsorption treatment, treated air will be emitted to the atmosphere via a stack located above the existing roof-line.
- Aqueous-phase activated carbon adsorption treatment will be included in the system design to provide additional polishing of the pretreated groundwater.
- The constituents in the groundwater will be similar in composition but higher in concentration than those observed during the pilot testing.
- The pretreatment system will be divided into three components — liquid-phase treatment, vapor-phase treatment, and sludge handling.
- The groundwater to be treated will not have free-phase non-aqueous components; constituents will be dissolved.

Appendix F

Former Production Area Groundwater Bench-Scale Study Analytical Report and Pre-Design Investigation Data Summary Tables

Technical Memorandum

To	Dr. Joseph Guarnaccia, BASF	Page	1
CC	Rory Henderson (AECOM); File		
Subject	Groundwater Bench Test Results for In Situ Bioremediation		
From	Tomasz Kalinowski, Joanne Lynch, Lucas Hellerich (AECOM)		
Date	February 6, 2015 rev. July 24, 2015		

Introduction

This Technical Memorandum presents the results and conclusions from a bench-scale treatability study evaluating anaerobic and aerobic in situ bioremediation as potential treatment technologies for contaminants of concern (COCs) present at the Former Ciba-Geigy Facility, currently owned by BASF Corporation, located at 180 Mill Street, Cranston, Rhode Island (the "Site"). The study began in September 2014 and was completed in April 2015.

The objective of the bench-scale test was to assess which of the evaluated bioremediation technologies is most efficient at enhancing the degradation of the Site contaminants. It is anticipated that the bench-scale test data will be used to further evaluate treatment alternatives at the Site to address COCs in Site groundwater.

Please note that table and figure references pertain to those included in the Laboratory Biotreatability Study to Evaluate Remediation of Chlorinated VOCs and TEX Compounds in Groundwater (SiREM, 2015), which is an attachment to this technical memorandum.

Background

The compounds chlorobenzene, 1,2-dichlorobenzene, 2-chlorotoluene, toluene, and xylenes were identified as COCs in groundwater at the Site. Media Protection Standards (MPS) were developed for these compounds in the Pawtuxet River Corrective Measures Study (Woodward-Clyde, 1996). Additional compounds, tetrachloroethylene (PCE) and vinyl chloride, are also present above RI DEM GB groundwater criteria in a limited area. The area of impact has been delineated and the impacted groundwater is migrating towards the Pawtuxet River.

Based on the screening process completed for the Site groundwater, three applicable groundwater remediation technologies were initially identified in the Corrective Measures Study (CMS): in situ chemical oxidation (ISCO) and both anaerobic and aerobic biodegradation. These technologies are documented in the scientific literature to effectively treat site COCs. The bench-scale test focused on anaerobic and aerobic biodegradation rather than ISCO, as ISCO will be tested in a field-scale pilot test.

Anaerobic Biodegradation

Anaerobic biodegradation is an option to treat COCs in the heterogeneous materials historically characterized as silt, or discontinuous aquitard, and shallow more permeable portions of the aquifer that are located near the bulkhead. The target COCs for treatment are 1,2-dichlorobenzene, chlorobenzene, 2-chlorotoluene, toluene, and xylenes. In addition, anaerobic biodegradation has been shown as an effective means of degrading chlorinated ethenes (e.g. PCE).

Description of Technology

Anaerobic biodegradation uses indigenous or introduced anaerobes to degrade COCs by two general mechanisms: using the contaminant as a metabolic terminal electron acceptor or an electron donor. Reduction of the contaminant (whereby it serves as an electron acceptor) requires an electron donor and carbon source to stimulate the microbial population. Once the competing electron acceptors (e.g. O₂, NO₃) are exhausted, sufficiently reducing conditions are established where dechlorination can occur. Chlorines on contaminants are typically replaced with hydrogen (e.g. trichloroethene [TCE] to cis-dichloroethene [cis-DCE], chlorobenzene transforms to benzene, 2-chlorotoluene to toluene, etc.). Alternatively, during contaminant oxidation (whereby it serves as an electron donor), an electron acceptor such as sulfate or nitrate is introduced. Sulfate is commonly applied to serve as an electron acceptor for treatment of benzene and toluene, though is typically less effective against chlorinated aromatics. Chlorinated ethenes will sequentially dechlorinate to ethene under appropriate anaerobic conditions and if the appropriate microbial populations (i.e. *dehalococcoides* sp.) are present.

Remedial Approach

The remedial approach for implementing anaerobic biodegradation in the Former Production Area (FPA) aquifer would include injection well and/or direct push injections of a carbon substrate and sulfate into the impacted portions of the aquifer.

Anaerobic biodegradation has documented success in treating chlorobenzene, 1,2-dichlorobenzene, 2-chlorotoluene, and chlorinated ethenes. The addition of sulfate will facilitate treatment of benzene, toluene, and xylenes under anaerobic conditions. The assumptions used for the remedial approach include using a carbon source and sulfate to enhance reducing conditions over several years. Carbon sources are generally made of food grade, non-hazardous products and can be used in the vicinity of the Pawtuxet River, however, metals may be temporarily mobilized under reducing conditions.

During injection activities, the carbon substrate and sulfate may be injected under pressure via injection wells or direct push applications to achieve distribution throughout the formation within the treatment intervals. Monitoring of the distribution of the carbon substrate and sulfate in-situ would be performed.

Aerobic Biodegradation

Aerobic biodegradation is an option to treat COCs in the heterogeneous materials historically characterized as silt, or discontinuous aquitard, and shallow more permeable portions of the aquifer located near the bulkhead. The target COCs for treatment are 1,2-dichlorobenzene, chlorobenzene, 2-chlorotoluene, toluene, and xylenes. In addition, aerobic biodegradation has been shown to degrade certain chlorinated ethenes (e.g., PCE, TCE).

Description of Technology

Aerobic biodegradation uses indigenous or introduced aerobes to biodegrade COCs in situ. Impacted aquifers are often oxygen-limited, therefore implementation of this technology frequently involves reintroducing oxygen to the aquifer to accelerate naturally-occurring in situ bioremediation. Pure oxygen or oxygen-releasing substances such as hydrogen peroxide, ozone, and commercial oxygen-releasing compounds are injected into the aquifer to provide an additional supply of oxygen to the subsurface, which then becomes available to aerobic bacteria.

There are two main pathways for aerobic biotransformation to progress, depending on the Site COCs. Single ring aromatic compounds containing less than two chlorines and chlorinated aliphatic compounds will degrade along two different pathways. Under aerobic or oxic conditions, biodegradation of single ring aromatic COCs (e.g., benzene, toluene, and their chlorinated congeners) proceed through oxidation of the carbon backbone, often to complete mineralization. Most frequently, the rate-limiting step is the activation of the aromatic ring that is required to enable its breakage. Depending on the species and metabolic capabilities present in the microbial community, the aromatic ring is catalyzed by a variety of mono- or dioxygenases that produce a transient catechol. The catechol is then rapidly degraded into simpler molecules which are then fed into a general metabolic pathway (e.g., Krebs cycle) where the carbon molecules are ultimately mineralized or assimilated for microbial growth. Intermediate degradation products of single ring aromatic COC oxidation are unfeasible and of little benefit to track as a performance tool since they are very transient in nature, the target COCs are degraded rapidly, and there are a wide diversity of degradation products that might be observed.

Under aerobic conditions, chlorinated aliphatics (e.g., PCE, TCE, DCE, and vinyl chloride) are significantly more persistent than single ring aromatics, with persistence correlating well with the number of chlorines present on the target molecule. TCE can be degraded co-metabolically under aerobic conditions, whereby a non-specific mono-oxygenase dechlorinates TCE, yielding lost energy for the microorganism. Co-metabolic aerobic destruction is better suited for low TCE concentrations because inhibition of activity is observed at higher TCE concentrations. The lighter chlorinated compounds vinyl chloride and dichloroethene can be degraded both co-metabolically and metabolically under aerobic conditions. For this reason, faster degradation rates are typically observed for these lighter chlorinated compounds.

Remedial Approach

The remedial approach for implementing aerobic biodegradation in the FPA aquifer would include commercially available oxygen diffusers installed into wells or direct push injections of an oxygen-releasing compound into a treatment interval within the aquifer.

Oxygen diffusers work passively under regulated oxygen tank pressure and diffuse pure oxygen into the groundwater. Groundwater with high concentrations of dissolved oxygen is then transported downgradient from the well. Another means of providing oxygen to the aquifer is through oxygen release compounds, which are generally made of food grade, non-hazardous products. Both applications can be used in the vicinity of the Pawtuxet River since they degrade to oxygenated groundwater.

An alternative approach has also been proposed where an ISCO technology (ozone sparging in this case) will be implemented in a barrier upgradient from the Pawtuxet River. While some direct oxidation of site COCs will occur, it is expected that the bulk of the byproduct of the ozone treatment (e.g. oxygen), will help to stimulate aerobic biodegradation within and downgradient from the

barrier. This alternative has been incorporated into the Draft CMS and evaluated against revised groundwater treatment technologies already incorporated.

Methods

Soil and groundwater were collected from areas in the vicinity of former Building 16 on September 11 and 12, 2014. Undisturbed soil samples were collected from 15 to 25 feet below ground surface (ft bgs) via Geoprobe, and macrocores were cut, capped, and prepared for shipping. Groundwater was collected from MP-3I. Soil and groundwater was shipped to SiREM laboratory in Guelph, Ontario, Canada. SiREM conducted the bench scale tests.

Microcosm Construction

Microcosms were constructed by filling 250 milliliter (ml) (nominal volume) glass bottles with approximately 200 ml of Site groundwater and 60 grams (g) of geologic material leaving a nominal headspace for gas production (e.g., carbon dioxide [CO₂] and/or methane). Anaerobic microcosms were constructed in a disposable anaerobic glove-bag and were stored and sampled in an anaerobic chamber to maintain anaerobic conditions. Aerobic microcosms were constructed similarly although they were stored, and sampled under aerobic conditions in a chemical fume hood. Microcosms were sealed with Mininert™ valves to allow repetitive sampling of each microcosm, and to allow addition of amendments to sustain metabolic/biodegradation activities.

The bench test consisted of four microcosm studies as outlined below.

Microcosm Studies

Treatment/Control	Description		Number of Replicates
1 ANSC -1 ANSC-2	Anaerobic Sterile Control	Autoclaved and amended with mercuric chloride and sodium azide	2
2 LAC/SO4-1 LAC/SO4-2	Lactate and Sulfate Amended	Amended with Lactate and sulfate (with optional ZVI and bioaugmentation)	2
3 NuSO4-1 NuSO4-2	Nutrisulfate Amended	Amended with Nutrisulfate	2
Aero-1 Aero-2 Aero-2-1 Aero-2-2	Aerobic Treatment	Amended with oxygen releasing compound and oxygen as required to maintain aerobic conditions	4, additional replicates were added as discussed below

Controls and treatments were constructed in duplicate. One replicate of each control and treatment was amended with resazurin to monitor redox conditions and microbial activity. Prior to start of the anaerobic bench test, the groundwater for the anaerobic sterile control microcosms was amended with mercuric chloride and sodium azide to inhibit microbial activity. The anaerobic geologic material

was autoclaved. Lactate combined with sulfate was evaluated. A treatment amended with sulfate (Nutrisulfate, Tersus Environmental) was also evaluated. The aerobic treatment microcosms were amended with an oxygen releasing compound (ORC-A) and supplemented three times a week with neat oxygen gas to maintain aerobic conditions.

Microcosm Spiking and Dosing

After baseline measurement of VOC concentrations in the microcosms and prior to initiating the tests, all microcosms were spiked to target VOCs concentrations as shown below:

Summary of Target VOC Concentrations in Microcosms

Target COC	Target concentration in microcosm (mg/L)
1,2-Dichlorobenzene	30
Chlorobenzene	10
2-Chlorotoluene	10
Toluene	20
Ethyl benzene	0.5
o-Xylene	0.4
m,p-Xylene	0.1
Tetrachloroethene	0.5
Trichloroethene	0.5
cis-1,2-dichloroethene	0.5
Vinyl chloride	0.4

Lactate and sulfate microcosms were amended with magnesium sulfate to a target concentration of 330 milligrams per liter (mg/l) sulfate at Day 0. Lactate amendment was conducted weekly for four weeks beginning at Day 64, to a target concentration of 12.5 mg/L at each amendment event.

Nutrisulfate microcosms were amended with 768 microliters (μl) of Nutrisulfate ("Nutrimens") to a target concentration of 500 mg/l sulfate at Day 0. Nutrimens amendment was conducted weekly for four weeks beginning on Day 64, with a target amendment concentration of 12.5 mg/L at each amendment event.

Aerobic microcosms were amended with 0.01 g ORC-A at Day 0 and were subsequently amended with 5 ml of neat oxygen gas three times a week. The first two aerobic microcosms (AERO-1-1, AERO-1-2) were spiked and not sampled within an appropriate amount of time to establish spiked baseline conditions, therefore, on Day 13, all compounds were re-spiked to original target concentrations. An additional set of two microcosms were constructed (named AERO-2-1, AERO-2-2) to effectively re-start the aerobic test (due to the very rapid degradation kinetics and lack of an adequate baseline sample at Day 0). These were sampled at Day 0.1 to capture the baseline.

Microcosm Incubation, Sampling, and Analysis

Aqueous samples were collected from the control and treatment microcosms every two to three weeks for analysis of VOCs and dissolved hydrocarbon gases (e.g., ethene, ethane, or methane). Table 2 presents the analytical data results for the chlorinated compounds, from each microcosm sampled.

Microcosms were analyzed for Anions (i.e., sulfate, nitrate, chloride, and phosphate) 5 times over the course of the experiment, and are reported in Table 3; pH values recorded are presented in Table 5. In addition, the electron donor amended microcosms were sampled for analysis of volatile fatty acids (e.g., lactate, acetate and propionate) to permit evaluation of electron donor fermentation and longevity (see Table 4). Dissolved metals were sampled three times, at baseline (day 0), while the study was ongoing (~ Day 60) and at the conclusion of the study (~Day 210). Table 6 presents the analytical results of the dissolved metals sampling.

Please note that tables referenced here pertain to the tables included in the Laboratory Biotreatability Study to Evaluate Remediation of Chlorinated VOCs and TEX Compounds in Groundwater (SiREM, 2015).

Results and Discussion

The analytical results of the anaerobic and aerobic bench-tests are summarized in this section. Full results are presented in the Laboratory Biotreatability Study to Evaluate Remediation of Chlorinated VOCs and TEX Compounds in Groundwater (SiREM, 2015) attached.

Graphical depictions of chlorinated compound trends are presented on Figures 2 through 6, and are discussed below. Note that each study used two replicates; the analytical results from each of the two replicates were averaged and are presented in the figures, with the exception of Figures 4A and 4B, where replicates are reported individually. Table 2 presents the VOC data for each of the replicates as well as the average concentration.

Please note that figures referenced here pertain to the figures included in the Laboratory Biotreatability Study to Evaluate Remediation of Chlorinated VOCs and TEX Compounds in Groundwater (SiREM, 2015).

Anaerobic treatment

Similar COC transformation trends were observed for both anaerobic treatments of (1) magnesium sulfate salt and (2) a proprietary mixture of sulfate and nutrients called Nutrisulfate:

- 1,2-dichlorobenzene concentrations decreased in Lactate and Sulfate amended microcosms, corresponding with a near 1:1 molar increase in chlorobenzene (indicating dechlorination of 1,2-dichlorobenzene to chlorobenzene); This same transformation was not observed in the NutriSulfate replicates.
- No benzene was detected, nor was there a clear decreasing trend in the molar sum of chlorinated benzenes, suggesting that chlorobenzene underwent no further transformation);
- Toluene concentrations decreased, indicating oxidation with sulfate serving as a terminal electron acceptor; Toluene was consumed completely in Lactate and Sulfate amended microcosms, and in 1 of 2 Nutrisulfate microcosms.

- 2-chlorotoluene concentrations were stable under anaerobic conditions;
- PCE and TCE decreased to ND, corresponding with molar equivalent conversion sequentially through cis-DCE, VC and finally innocuous Ethene. An extended lag period was observed before dechlorination beyond cDCE commenced, with production of vinyl chloride not observed until day 153 in the Lactate and Sulfate amended microcosms.
- Sulfate data indicates that a large mass of the amended sulfate in both Nutrimens and Lactate and Sulfate treatment microcosms was consumed during the course of the experiment. Sulfate had been largely exhausted within the Lactate and Sulfate microcosms at the end of the treatability study, and nearing exhaustion in the Nutrisulfate microcosms.
- Total VFA results were consistent with the understanding of the experiment. Background values were in the range of 10 mg/L, and decreased steadily in microcosms unless amended. Individual VFAs were quantified in amended anaerobic microcosms at baseline, Days 97, 153, 186, and 217. By Day 97, all VFAs detected had been converted from lactate (or any other electron donors potentially present in the proprietary mixture of Nutrisulfate) to acetate. Acetate would be expected serve as an electron donor for dechlorination, but not until competing electron acceptors like sulfate had been consumed. Transient production of propionate, formate, and pyruvate was observed, but no accumulation of these VFAs was observed. Acetate was the only VFA found to accumulate.
- Despite the addition of lactate and other organic matter to the anaerobic microcosms, the pH remained steady in all treatment groups in the range of pH 6-7. This would indicate the groundwater was sufficiently buffered to maintain pH within a range that supports bioremediation in a well-mixed reactor; and

Figures 2 through 4 present graphical plots of the chlorinated compound concentration trends over time.

Based on these results, sulfate addition (with or without supplemental nutrients or lactate) would only be an effective treatment for toluene. No other Site COCs were significantly oxidized using sulfate as a terminal electron acceptor. Modest reductive dechlorination of a subset of Site COCs was able to proceed in the presence of sulfate (i.e., 1,2-dichlorobenzene and chlorinated aliphatics), though reduction of other COCs did not occur and may be inhibited (primarily chlorobenzene and 2-chlorotoluene). Current Site data indicates that dechlorination of Site COCs is occurring and sulfate addition at this time would be counterproductive by potentially inhibiting this natural attenuation mechanism, and not providing a suitable alternative transformation pathway.

Aerobic Treatment

Of the evaluated treatments, the aerobic microcosms showed the most rapid decrease in COC concentrations. Degradation of the five COCs from spiked concentrations to below their respective Media Protection Standards (MPS) ranged between 9 and 43 days. Corresponding plots of chlorinated compound concentration trends can be seen in Figures 5 and 6. Note that the shorter timeline on the x-axis of the aerobic studies (i.e., Figures 5 and 6) compared with the anaerobic studies (shown on Figures 3 and 4) reflects the more rapid degradation of compounds under aerobic conditions.

The rapid rates of aromatic COC degradation are consistent with the literature, however the degradation rates for chlorinated aliphatics (PCE, TCE, DCE, VC) are potentially a laboratory

artifact of the low starting concentrations near the method detection limit, and not indicative of any true transformation that may have occurred in the lab, but should be confirmed in the field.

Due to the use of the Mininert valves on the microcosms, potential volatile losses during oxygen addition are expected to be minimal, and are unlikely to impact our overall conclusions of the testing.

Anion, pH, and VFA data support the interpretation of data. Increasing chloride concentrations are expected to coincide with contaminant mass destruction; this increasing trend was observed in aerobic treatment microcosms. The aerobic microcosm also showed an increasing trend in sulfate over the course of the experiment (from an averaged baseline of 24 mg/L to 94 mg/L). This increasing trend was most likely due to the oxidation of organic sulfur or sulfides that are present in the site material (reduced sulfur compounds are commonly found in reducing environments). This result indicates that aerobic treatment may result in modest sulfate production in the field.

Other anions measured, nitrate, nitrite, and phosphate, were all near or below the detection limit throughout the course of the experiment for all treatment groups.

Despite the production of chloride in the aerobic microcosms, the pH remained steady in all treatment groups in the range of pH 6-7. This would indicate the groundwater was sufficiently buffered to maintain pH within a range that supports bioremediation in a well-mixed reactor. However, buffer amendment may still be recommended in a field application, where heterogeneous conditions prevail.

Degradation Rates

A first order degradation constant (k) was calculated for each of the treatments. The rate constant was calculated as follows:

$$\text{half-life} = \frac{\ln(2) (t_{\text{final}} - t_0)}{\ln(C_{\text{final}}) - \ln(C_0)}$$

Where,

C_0 was the concentration at the start of the experiment (time, t_0), unless the COC concentration increased after Day 0 due to delayed soil sorption/desorption equilibrium kinetics, or unless the compound was produced during the experiment as a byproduct of other transformations.

Concentration C_{final} was the concentration at the conclusion of the experiment; if the compound was ND, one-half of the method detection limit was used for purposes of the calculation; and

Time t_{final} was the time at the conclusion of the experiment, or the timepoint at which the COC was no longer detectable, whichever came sooner.

Contaminant half-lives are presented in Table C, below. Higher values indicate slower degradation kinetics. Uncalculated half-lives ("–") indicate a compound concentrations increased over the course of the experiment values.

Half-lives (days) – Anaerobic Degradation			
COC	Lactate and Sulfate	Nutrisulfate Replicate 1	Nutrisulfate Replicate 2
Toluene	30	36	465
2-Chlorotoluene	345	304	399
Chlorobenzene	-	-	502
1,2-Dichlorobenzene	19	179	373
o-Xylene	587	377	314
Ethyl Benzene	536	297	328
Tetrachloroethene	7.3	3.9	3.2
Trichloroethene	19	4.3	4.2
<i>cis</i> ,1-2-dichloroethene	24	23	487
Vinyl Chloride	11	25	-

Aerobic degradation has substantially higher degradation rates for the Site COCs toluene, 2-chlorotoluene, chlorobenzene, 1,2-dichlorobenzene, and xylenes. Aerobic degradation occurs at a lower rate for the chlorinated ethenes PCE, TCE, *cis*-1,2-DCE, and VC. Vinyl chloride is also expected to aerobically degrade.

While batch bottle microcosm studies are ideal for comparative ranking of remediation technologies based on observed first order degradation rates, lab-derived degradation rates are qualitative and should not be used to make projections about performance in the field. It is typical to observe a 2-5 fold difference between lab and field degradation rates, and is not uncommon to see an order of magnitude difference or more. Laboratory rates tend to overestimate field degradation rates for a variety of reasons, specifically, maintaining good contact between reagents, temperature, higher water to soil ratio (limiting sorption and making COCs more bioavailable), and selection of favorable reagent dosing.

An additional factor impacting aqueous COC concentrations (and the degradation kinetics they are used to calculate) is desorption kinetics, which are typically slower than (ad)sorption kinetics. Upon introducing COCs to the microcosms, a relatively long period of time is required before contaminants reach equilibrium between being sorbed to soil and dissolved in water. The anaerobic sterile control (Figure 2), indicated that the majority of the compounds had not reached equilibrium until Day 14, with the exception of 1,2-dichlorobenzene and 2-chlorotoluene, which had not reached equilibrium until Day 28. Lactate and sulfate and nutrisulfate amended microcosms exhibited a similar timeline, with the concentration of COCs in water continuing to rise through Day 28 for 1,2-dichlorobenzene, chlorobenzene, and 2-chlorotoluene, as well as toluene. However, both the peak and the rate of concentration increase of COC aqueous concentrations were significantly greater in the two anaerobic treatment microcosms. This is potentially due to the increased solubilization of COCs being driven by secretion of biosurfactant or other extracellular polymeric substances (EPS) by the stimulated microbial community (Ron and Rosenberg, 2001). One known function of EPS is to facilitate desorption and solubilization of nutrients or energy sources, as compounds sorbed to solids are not readily bioavailable. It is possible that a similar, microbially-driven enhanced solubilization also occurred in the aerobic microcosms, but was masked by the rapid degradation kinetics.

Conclusion/Recommendations

The batch microcosm study indicates that aerobic treatment will produce the fastest degradation kinetics for Site COCs. All Site COCs were reduced to below their respective MPS between 9 and 43 days of aerobic treatment in the laboratory. This result is consistent with the literature and thermodynamics. However the primary challenge with field implementing an aerobic approach will be achieving sufficient oxygen delivery and distribution. It is possible that zones of anaerobic conditions will exist, and as such, it is important to understand biotransformations that may occur under anaerobic conditions.

Sulfate is a desirable amendment due to its low cost and high solubility in groundwater, however, the treatability study indicated that under sulfate-reducing conditions, degradation of dichlorobenzene, chlorobenzene, 2-chlorotoluene and DCE would be negligible, with only degradation of toluene occurring. Only modest dechlorination of dichlorobenzene to chlorobenzene was observed, and essentially none for 2-chlorotoluene. Chlorinated aliphatics PCE and TCE were relatively rapidly degraded to DCE, however further dechlorination to VC or ethene was observed only after a lengthy lag period during which time sulfate concentrations had decreased significantly. These results are also consistent with the literature and thermodynamics; sulfate competes with the lightly chlorinated COCs as an electron acceptor. For these reasons, sulfate addition is not recommended. The treatability study demonstrated that it may inhibit dechlorination of lighter chlorinated COCs by competing as an electron acceptor. It also is not a suitable electron acceptor for any of the chlorinated COCs. Sulfate addition would accelerate degradation of BTEX, but could retard or inhibit dechlorination of chlorinated COCs. Since this outcome is not acceptable, sulfate addition is not recommended.

Aerobic treatment may not be completely effective for biodegradation of PCE, and can be expected to have only limited effectiveness for TCE and cDCE. Aerobic degradation of vinyl chloride will occur.

Recommendations

Based on this set of bench-scale studies, aerobic biodegradation is expected to be effective for Site COCs. The degradation rates of 1,2-dichlorobenzene, chlorobenzene, 2-chlorotoluene, toluene, and xylenes are much higher under aerobic conditions compared to anaerobic conditions. While an ISCO approach consisting of an ozone barrier is currently being proposed and considered, oxygen resulting from ozone treatment will likely provide a robust secondary treatment mechanism based on the results of the bench-scale work. If there are any questions concerning the information contained within this draft technical memorandum, please feel free to contact Joanne Lynch or Lucas Hellerich at (860) 263-5783 (lucas.hellerich@aecom.com).

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Final Report

Laboratory Biotreatability Study to Evaluate Remediation of Chlorinated VOCs and TEX Compounds in Groundwater

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Appendix A:	Chain of Custody Documentation
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LIST OF ABBREVIATIONS

ALS	ALS Environmental
BMO	butane mono-oxygenase
CB	chlorobenzene
2-CT	2-chlorotoluene
CO ₂	carbon dioxide
<i>Dhc</i>	<i>Dehalococcoides</i>
°C	degrees Celsius
°C/min	degrees Celsius per minute
1,2-DCB	1,2-dichlorobenzene
cDCE	<i>cis</i> -1,2-dichloroethene
DHG	dissolved hydrocarbon gases
Fe ³⁺	ferric iron
Fe ²⁺	ferrous iron
ERD	enhanced reductive dechlorination
GC	gas chromatograph
g	grams
IC	ion chromatograph
Fe	iron
L	liter
Mn	manganese
Mn ²⁺	manganese (II)
Mn ⁴⁺	manganese (IV)
µg/L	micrograms per liter
µL	microliter
µm	micrometer
min	minutes
mg/L	milligrams per liter
mL	milliliters
mL/min	milliliters per minute
mM	millimolar
mmol/bottle	millimoles per bottle
MMO	methane mono-oxygenase
MO	mono-oxygenase
ORC®-A	Oxygen Release Compound® - Advanced
%	percent
psi	pounds per square inch
PMO	propane mono-oxygenase
QL	quantitation limit
RPM	revolutions per minute
SGS	SGS Environmental
SiREM	SiREM Laboratory
PCE	tetrachloroethene

LIST OF ABBREVIATIONS
CONTINUED

TEX	toluene, ethyl benzene, o-xylene
TMO	toluene mono-oxygenase
TCE	trichloroethene
VC	vinyl chloride
VFA	volatile fatty acid
VOA	volatile organic analysis
VOC	volatile organic compound

1. INTRODUCTION

AECOM retained SiREM Laboratory (SiREM) to perform a laboratory biotreatability study to assess the potential for in situ bioremediation of chlorinated ethenes, chlorinated aromatics and aromatics in groundwater at a site in Cranston, Rhode Island (the Site). The purpose of the study was to assess aerobic and anaerobic biodegradation of the target Site compounds namely 1,2-dichlorobenzene (1,2-DCB), chlorobenzene (CB), 2-chlorotoluene (2-CT), toluene, ethyl benzene and xylene (TEX), and tetrachloroethene (PCE), trichloroethene (TCE), cis-1,2-dichloroethene (cDCE), and vinyl chloride (VC).

The geologic materials (TS-1 15'-23') and groundwater (MP-3I) used in this study were collected by AECOM personnel on 11 September 2014. The geologic material was received by SiREM on 12 September 2014 and the groundwater was received 15 September 2015. Refer to Appendix A for the chain of custody documentation received with the materials.

The remainder of this report contains a summary of key biodegradation processes (Section 1.1), the experimental materials and methods (Section 2), the results and discussion of the microcosm study (Section 3), conclusions (Section 4) and report references (Section 5).

1.1 Summary of Biodegradation Processes

Natural attenuation processes can occur in situ and are often mediated by indigenous microbial populations present at contaminated sites. Enhanced reductive dechlorination (ERD) can, in certain cases, be achieved by stimulating the indigenous microbial populations through the addition of electron donors. Anaerobic biological degradation products of PCE include TCE, cDCE, VC and the fully dechlorinated end product ethene. *Dehalococcoides* [*Dhc*] organisms are known to be responsible for mediating the complete dechlorination of PCE, TCE, cDCE and VC to ethene (Middledorp et al., 1999).

Enhanced aerobic degradation of chlorinated ethenes, can in certain cases, be achieved through the addition of oxygen or oxygen releasing compounds increasing the metabolic activities of indigenous microbial populations. Some bacteria produce mono-oxygenase enzymes (MOs) that are able to mediate aerobic degradation of chlorinated ethenes such as TCE. There are various types of MOs that have been found to promote TCE degradation, including: methane mono-oxygenase (MMO), butane mono-oxygenase (BMO), propane mono-oxygenase (PMO), and toluene mono-oxygenase (TMO). Figure 1 contains degradation pathways for the chlorinated ethenes degradation under anaerobic and aerobic conditions.

1,2-DCB, CB, 2-CT, toluene and benzene can also be biodegraded through a variety of pathways, under both aerobic conditions and select anaerobic (i.e., iron, nitrate, or sulfate reducing and methanogenic) conditions, with biodegradation products including catechol, carbon dioxide (CO₂) and methane (Liang et al., 2008).

2. MATERIALS AND METHODS

The following sections describe the materials and methods used for microcosm construction and incubation (Section 2.1), and microcosm sampling and analysis (Section 2.2).

2.1 Microcosm Construction, Incubation and Amendments

2.1.1 Microcosm Construction and Incubation

Biotreatability microcosms were constructed in a disposable anaerobic glove bag containing the Site groundwater and geologic material and all of the materials required to construct the treatment and control microcosms. The glove bag was purged with nitrogen gas in order to create an anaerobic environment and to protect any microorganisms present in the site materials from oxygen exposure. Prior to microcosm construction the Site geologic materials were homogenized by passing materials from the cores through a ½ inch sieve and mixing by hand. During microcosm and reactor construction, the Site water was mixed thoroughly to ensure reproducibility between replicates.

Microcosms were constructed by filling sterile 250 mL (nominal volume) screw cap Boston round clear glass bottles (Systems Plus, New Hamburg, ON) with 60 grams (g) of homogenized geologic material and 200 milliliters (mL) of Site groundwater on 17 September 2014 (Day -8). The bottles were capped with Mininert™ closures to allow repetitive sampling with minimal volatile organic compound (VOC) losses and to allow nutrient amendment, as needed, throughout the incubation period. All treatment and control microcosms were constructed in duplicate.

After initial microcosm construction, the original aerobic microcosms were removed from the anaerobic glove bag and the closures opened to expose them to atmospheric oxygen and improve the aerobic conditions in the microcosms. The original aerobic microcosms were additionally incubated on the lab bench for 7 days before VOC amendment and 8 days before the start of the study.

Table 1 summarizes the details of microcosm construction and the amendments used for the treatment and control microcosms.

On 7 October 2014 (Day 12 of the original study, Day -1 for these two microcosms), two new aerobic microcosms were constructed to verify the VOC results obtained from the original aerobic microcosms. The new microcosms were constructed in the same fashion as the original microcosms. Details of the construction, spiking, and amendment of the new microcosms are provided in Table 1.

Anaerobic sterile control microcosms were constructed to quantify potential abiotic and experimental VOC losses from the microcosms. The sterile controls were constructed by autoclaving the Site geologic materials at 121 degrees Celsius (°C) and 15 pounds per square inch (psi) pressure for 45 to 60 minutes (min). After autoclaving, the sterile control microcosms

were returned to the anaerobic chamber, filled with 200 mL of Site groundwater and amended with mercuric chloride and sodium azide as described in Table 1.

All anaerobic microcosms were sampled and incubated in an anaerobic chamber (Coy Laboratory Products, Grass Lake, MI) filled with an atmosphere of approximately 80 percent (%) nitrogen, 10% CO₂ and 10% hydrogen (Linde Gases, Guelph, ON). Hydrogen in the anaerobic chamber functions to scavenge trace oxygen via a palladium catalyst. Anaerobic conditions in the anaerobic chamber were verified using an indicator containing resazurin (Sigma, St. Louis, MO) in a mineral medium, which turns pink in the presence of oxygen. During quiescent incubation, the anaerobic microcosms were covered to minimize photodegradation and stored horizontally to minimize VOC losses via the (submerged) Mininert™ closure. Microcosms were incubated for a period of up to 217 days at approximately 22 °C (room temperature).

Aerobic microcosms were stored on the lab bench. During quiescent incubation, the aerobic microcosms were covered to minimize photodegradation and stored horizontally to minimize VOC losses via the submerged Mininert™ closure. The aerobic microcosms were incubated for a period of up to 62 days at approximately 22 °C (room temperature).

2.1.2 Microcosm Amendments

AECOM specified that the initial PCE, TCE, and cDCE concentrations should be approximately 0.5 milligrams per liter (mg/L) each. Additionally, the initial 1,2-DCB, CB, and 2-CT concentrations should be 30, 10, and 10 mg/L, respectively. The initial target concentrations of the TEX compounds were specified by AECOM to be 20 mg/L, 0.5 mg/L, and 0.4 mg/L for toluene, ethyl benzene, and *o*-xylene, respectively. TCE, cDCE, the chlorinated aromatic compounds and TEX compounds were not at the specified target concentrations in the prepared microcosms; therefore the microcosms were amended with the target compounds on 24 September 2014 (Day -1). A custom solution of the target compounds (in neat form) was prepared to allow a single addition of 14 microliters (μL) of the custom stock solution to all microcosms to reach the target concentrations. On 7 October 2014 (Day 12 of the original study, Day -1 of the new microcosms) the original and new aerobic treatment microcosms were amended with 14 μL of the custom compound solution. Details of microcosm spiking are provided in Table 1 and Table 2.

Anaerobic treatment microcosms were initially amended with a magnesium sulfate (Bioshop, Burlington, ON) solution or Nutrisulfate® (Tersus Environmental LLC, Raleigh, NC) on 25 September 2014 (Day 0). Starting on 28 November 2014 (Day 64) the anaerobic treatment microcosms were amended with electron donor on a weekly basis. The magnesium sulfate amended microcosms were amended with a 6 % lactate solution (JRW Bioremediation, Lenexa, KS); the Nutrisulfate amended microcosms were amended with liquid Nutrimens® (Tersus Environmental LLC, Raleigh, NC) as electron donors.

The aerobic treatment microcosms were initially amended with 0.01 g of oxygen release compound® – advanced (ORC®-A – Regenesis, San Clemente, CA) on 25 September 2014 (Day 0 for the original aerobic microcosms) and on 8 October 2014 (Day 0 of the new aerobic

microcosms). The aerobic microcosms were then amended with 5 mL of oxygen gas three times a week (Monday, Wednesday, and Friday) through the Mininert™ septa until 26 November 2014 (Day 62 of the original study, Day 43 of the new microcosms) when the aerobic microcosms were completed.

The first microcosm of each treatment and control was amended with resazurin (Sigma, St. Louis, MO) to monitor redox conditions. Resazurin turns from pink to clear in the absence of oxygen and can be used to indicate the on-set of reducing conditions. Details of target compound spiking, treatment amendments and resazurin amendment are provided in Tables 1 and 2.

2.2 Microcosm Sampling and Analysis

2.2.1 Microcosm Sampling

Aqueous samples were collected from the control and treatment microcosms on a biweekly (i.e., every two weeks) and later monthly basis for analysis of VOCs, dissolved hydrocarbon gases (DHGs – ethene, ethane, and methane) and pH. Aqueous samples were also collected less frequently for analysis of volatile fatty acids (VFAs – lactate, acetate, propionate, formate, butyrate and pyruvate) and anions (sulfate, nitrate, nitrite, chloride, phosphate, bromide). The microcosms were sampled using gas-tight 250 µL and 1 mL Hamilton glass syringes. Syringes were cleaned with acidified water (pH ~2) and rinsed 10 times with deionized water between samples to ensure that VOCs and microorganisms were not transferred between different samples or treatments. The analytical methods employed by SiREM are described below.

Baseline analysis of VOCs was completed at the beginning of the study at ALS Environmental (ALS – Waterloo, ON). Analysis of dissolved metals was completed at the beginning of the study and at the endpoint of each treatment at SGS Environmental (SGS – Lakefield, ON). The sampling methods employed by SiREM and the external laboratories are described below.

2.2.2 Analysis of VOCs and DHGs

This section describes the methods used to quantify the chlorinated ethenes, chlorinated aromatics, TEX compounds, DHGs and benzene. The quantitation limits (QL) for the VOCs and DHGs were typically 100 micrograms per liter (µg/L) in the microcosms based on the lowest concentration standards that were included in the linear calibration trend.

Aqueous VOC and DHG concentrations in the microcosms were measured using a Hewlett-Packard (Hewlett Packard 7890) gas chromatograph (GC) equipped with an auto sampler (Hewlett Packard G1888) programmed to heat each sample vial to 75°C for 45 min prior to headspace injection into a GSQ Plot column (0.53 millimeters x 30 meters, J&W) and a flame ionization detector. Sample vials were heated to ensure that all VOCs in the aqueous sample would partition into the headspace. The injector temperature was 200°C, and the detector temperature was 250°C. The oven temperature was programmed as follows: 35°C for 2 min, increased to 100°C at 30 degrees Celsius per minute (°C/min), then increased to 185°C at 25°C/min and held at 185°C for 7 min, then followed by an increase to 225 °C at 25 °C/min and

held at 225 °C for 10 min. The carrier gas was helium at a flow rate of 11 milliliters per minute (mL/min).

After withdrawing a 100 µL sample (as described in section 2.2.1), the sample was injected into a 10 mL auto sampler vial containing 5.9 mL of acidified deionized water (pH ~2). The water was acidified to inhibit microbial activity between microcosm sampling and GC analysis. The vial was sealed with an inert Teflon[®]-coated septum and aluminium crimp cap for automated injection of 3 mL of headspace onto the GC. One VOC standard was analysed with each set of samples to verify the instrument five-point calibration curve. Calibration was performed using external standard solutions (Sigma, St Louis, MO), where known volumes of standard solutions were added to acidified water in auto sampler vials and analysed as described above for microcosm samples. Data were integrated using Chemstation Software (Agilent Technologies, Santa Clara, CA).

2.2.3 Analysis of Anions and Total Volatile Fatty Acids

Anion analysis was performed on a Thermo-Fisher ICS-2100 ion chromatograph (IC) equipped with a Thermo-Fisher AS-DV auto sampler and an AS18 column. An isocratic separation was performed using 33 millimolar (mM) reagent grade sodium hydroxide (Thermo Scientific, Oakville, ON) eluent for 15 min at a flow rate of 0.25 mL/min. The sample loop volume was 25 µL. One standard was analysed with each set of samples tested in order to verify the seven-point calibration using external standards of known concentrations. External standards were prepared gravimetrically using chemicals of the highest purity available (Sigma St Louis, MO or Bioshop, Burlington, ON). Data were integrated using Chromeleon 7 Chromatography software (Thermo Scientific, Oakville, ON). The QLs were as follows: 0.07 mg/L total VFAs, 0.07 mg/L chloride, 0.09 mg/L nitrite, 0.09 mg/L nitrate, 0.07 mg/L sulfate, 0.07 mg/L phosphate and 0.08 mg/L bromide.

A 0.5 mL sample was withdrawn (as described in section 2.2.1), after which the sample was placed in a 1.5 mL micro-centrifuge tube. Samples were centrifuged for five minutes at 13,000 revolutions per minute (RPM) to remove solids. The supernatant was sub-sampled, diluted 50-fold in deionized water and placed in a Thermo-Fisher auto sampler vial with a cap that filters the sample during automated injection onto the IC.

2.2.4 Analysis of VFAs

Individual VFAs (lactate, acetate, propionate, formate, butyrate and pyruvate) analysis was performed on a Thermo-Fisher ICS-2100 IC equipped with a Thermo-Fisher AS-DV auto sampler and an AS11-HC column. A gradient separation was performed using the following eluent profile; 1.0 mM sodium hydroxide for 8.0 min to 15 mM at 18.0 min and proceeding to 30 mM at 28.0 min with a flow rate of 0.25 mL/min. The sample loop volume was 25 µL. Calibration was performed using external standards of known concentrations. One standard was analysed with each set of samples to verify the instrument's seven-point calibration curve produced using external standards of known concentrations. External standards were prepared gravimetrically using chemicals of the highest purity available (Sigma St Louis, MO or Bioshop, Burlington,

ON). Data were integrated using Chromeleon 7 chromatography software (Thermo Scientific, Oakville, ON). The QLs were as follows: lactate 0.40 mg/L, acetate 0.54 mg/L, propionate 0.31 mg/L, formate 0.23 mg/L, butyrate 0.41 mg/L and pyruvate 0.69 mg/L.

A 0.5 mL sample was withdrawn (as described in section 2.2.1), after which the sample was placed in a 1.5 mL micro-centrifuge tube. Samples were centrifuged for five minutes at 13,000 RPM in a micro-centrifuge to remove solids. The supernatant was sub-sampled, diluted 50-fold in deionized water and placed in a Thermo-Fisher auto sampler vial with a cap that filters the sample during automated injection onto the IC.

2.2.5 Analysis of pH

The pH measurements were performed using an Oakton pH spear with a combination pH electrode (Oakton, Vernon Hills, IL). A 0.5 mL sample was taken and placed into a 1.5 mL micro-centrifuge tube (as described in section 2.2.1). The tube was removed from the glove box and the pH was measured on the lab bench. The pH spear was calibrated at each sampling event according to the manufacturer's instructions using pH 4.0, 7.0 and 10 standards.

2.2.6 Baseline External Analysis of VOCs at ALS

Baseline analysis of VOCs was completed at ALS in Waterloo, ON to verify the target compound spiking concentrations. Two sacrificial microcosms were prepared on 17 September 2014 (Day -8) and spiked with the target compounds on 24 September 2014 (Day -1). The sacrificial microcosms were sampled on 25 September 2014 (Day 0) in two 40 mL volatile organic analysis (VOA) vials per microcosm. Samples were collected leaving no headspace and preserved with sulphuric acid. The VOA vials were stored at 4 °C overnight and collected by ALS in Waterloo, ON 26 September 2014 (Day 1). Refer to Appendix C for the ALS laboratory reports.

2.2.7 External Analysis of Dissolved Metals at SGS

Analysis of dissolved metals was completed at SGS in Lakefield, ON. A volume of 100 mL was sampled from sacrificial microcosms using Luer-lock 60 mL sterile syringes (Fisher, Whitby, ON). The sample was filtered using a 0.45 micrometer (µm) nylon syringe filter (Mandel, Guelph, ON) into a 125 mL polypropylene bottle preserved with nitric acid. The filtered/preserved samples were shipped overnight on ice to SGS for analysis. Refer to Appendix C for the SGS laboratory reports.

3. RESULTS AND DISCUSSION

The following sections present and discuss the results of the biotreatability study:

- Redox Processes (Section 3.1),
- Chlorinated Ethenes, Chlorinated Aromatics, and TEX Half-Life calculations (Section 3.2),
- Anaerobic Sterile Control Results (Section 3.3),
- Lactate and Sulfate Amended Treatment Results (Section 3.4),
- Nutrisulfate[®] and Nutrimens[®] Amended Treatment Results (Section 3.5), and
- Aerobic Treatments Results (Section 3.6)

Tables 2, 3, 4, 5, and 6 provide VOC, ethene, ethane, methane, anion, VFA, pH and aqueous metals data from the control and treatment microcosms over the incubation period for the study. All VOC, ethene, ethane, and methane concentrations are presented in units of mg/L and millimoles per microcosm bottle (mmol/bottle) to present the data on a mass basis. Concentrations were converted from mg/L to mmol/bottle using Henry's Law as demonstrated in Appendix D. Table 7 presents the VOC half-lives and Figures 2 through 6 present trends in the concentrations of the chlorinated ethenes, chlorinated aromatics, TEX, and DHGs in the control and treatment microcosms over the incubation period for the study.

3.1 Redox Processes

The addition of electron donor typically results in microbial activity that promotes changes in the redox conditions in groundwater. Aerobic or mildly reducing redox conditions will be reduced, resulting in more strongly reducing conditions required to support anaerobic degradation of chlorinated VOCs.

The sequence of redox reactions in groundwater is well known (Appelo and Postma, 1994). Oxygen is first consumed, followed by nitrate (denitrification), iron (Fe), manganese (Mn), and sulfate reduction. Ferric iron (Fe^{3+}) is reduced to ferrous iron (Fe^{2+}), Manganese (Mn^{4+}) is reduced to manganese (Mn^{2+}) and sulfate is reduced producing sulfides. The final step is CO_2 reduction producing methane (methanogenesis). The consumption of each species in sequence indicates that conditions are becoming increasingly reducing. Dechlorination of chlorinated ethenes typically occurs in the range of sulfate reducing to methanogenic conditions. Anaerobic degradation of chlorinated aromatic compounds and TEX compounds can occur co-metabolically with the reduction of sulfate or CO_2 (Liang et al., 2008).

Aerobic redox processes are dominated by the presence of oxygen, which acts as the ultimate electron acceptor. Compounds present can react with oxygen resulting in the compounds present to reach their most oxidized state. Nitrogen is oxidized to nitrate, sulfur is oxidized to

sulfate, Fe and Mn are oxidized to Fe^{3+} and Mn^{4+} . Further, all carbon containing compounds can be oxidized to CO_2 , water, and simple anions (i.e., chloride).

3.2 Degradation Half-Lives for VOCs

Laboratory half-lives were calculated based on the average degradation observed in the control and treatment microcosms as indicated in Table 7. First order reaction kinetics were assumed for all calculations as described by Newell et al (2002). Where compounds decreased in concentration to below the detection limit, a value of one-half the detection limit was used for C_2 . The half-lives were calculated using the following relationship:

$$\text{Half-life} = \frac{\ln(2)}{\left[\frac{\ln\left(\frac{C_2}{C_1}\right)}{t_2 - t_1} \right]}$$

where,

C_1 is the concentration at an early time (t_1 days)

C_2 is the concentration at a later time (t_2 days)

Based on the data collected, the calculated half-lives for the chlorinated ethenes, chlorinated aromatics, TEX and all their intermediate degradation products were determined (Table 7). Half-lives are presented for each control or treatment below in their respective results section (Sections 3.3 to 3.6).

3.3 Anaerobic Sterile Control Microcosms

In the sterile control microcosms, nitrate and sulfate concentrations remained relatively stable (Table 3) and dissolved Fe and Mn increased slightly (Table 6). Methane concentrations did not increase (Table 2) which suggests that strongly reducing conditions were not achieved in the sterile control microcosms.

The pH in the sterile control microcosms stayed relatively stable, around 5.7, for the first 56 days of the study (Table 5). By Day 217, the pH had increased to an average of 6.24. This observed increase is likely a result of trace oxygen in the microcosms slowly being abiotically reduced to hydroxide or water, resulting in a slightly higher pH.

After an initial equilibration period, the concentrations of the chlorinated ethenes, chlorinated aromatics, TEX and DHGs in the sterile control microcosms remained stable for the duration of the study (Figure 2 and Table 2). PCE, 1,2-DCB, 2-CT, and CB (four of the least water-soluble compounds), increased in concentration from Day 0 to Day 14, then, with the exception of PCE, remained relatively stable. This initial increase suggests that these compounds required more time to come to full equilibrium between the aqueous and geologic material phases. PCE was observed to decrease below the detection limit in the second replicate of the sterile control

microcosms by Day 153. PCE also partially decreased in concentration to 0.49 mg/L by Day 217 in the first replicate. TCE was observed to increase in both replicates suggesting that some abiotic degradation of PCE to TCE may have occurred. A half-life of 110 days was calculated for PCE (Table 7). A half-life for TCE was not calculated because it increased in concentration over the incubation period. The Half-lives for the remaining compounds were all high indicating that the compounds remained relatively stable over the incubation period (Table 7). These observations are consistent with low levels of microbial activity expected in sterile control microcosms.

3.4 Sulfate and Lactate Amended Microcosms

In the lactate and sulfate amended treatment microcosm's sulfate reduction was not observed until after the addition of lactate was started on Day 64 (Table 3). This suggests that bacteria intrinsic to the site were not capable of using the TEX compounds or chlorinated aromatics as electron donors for sulfate reduction. After the weekly additions of lactate, sulfate was reduced to below the detection limit in the first replicate by Day 186 and had been partially reduced in the second replicate to 54 mg/L by Day 217 from an average concentration of 311 mg/L at time zero. Dissolved Fe was observed to decrease in concentration over the duration of the study; dissolved Mn also decreased slightly (Table 6). This suggests that the metals reduced to their more soluble forms, Fe^{2+} and Mn^{2+} , then likely precipitated out of solution with the sulfide produced from sulfate reduction or from hydroxides produced from oxygen reduction. Methane was not observed to increase over the incubation period. These results indicate that sufficiently reducing conditions for dechlorination were achieved in these microcosms, but strongly reducing methanogenic conditions were not achieved.

The pH in the lactate and sulfate amended microcosms initially remained stable over the first 96 days of the study (Table 5). After this period, the pH began to increase in concentration to 7.01 by Day 217. Sulfate reduction is an acid consuming process and can produce basic carbonates. These results suggest that the sulfate reduction that occurred in this treatment resulted in the slow increase in pH. The optimum pH for reductive dechlorination is 6.8 to 7.5 (Middledorp et al., 1999) and complete dechlorination can occur between a pH range of 6.0 and 8.0 (SiREM, unpublished data).

Lactate was not detected above the detection limit over the incubation period (Table 4). However, acetate was observed to increase in concentration at every sampling point after the weekly additions of lactate. This suggests that the lactate was fermented to acetate after each addition. The fermentation of the lactate to acetate results in the production of hydrogen, the ultimate electron donor used by dechlorinating bacteria.

Initial chlorinated ethenes, chlorinated aromatics, and TEX concentrations increased from Day 0 to Day 28 for all compounds present, indicating that a longer equilibration time between the aqueous and geologic material phases was required, especially for the more hydrophobic compounds, such as PCE, 1,2-DCB, 2-CT, CB, and toluene.

Complete dechlorination of PCE through TCE, cDCE, and VC to ethene was observed in both replicates by Day 186 (Figure 3 and Table 2). Half-lives of 7.3 days, 19 days, 24 days, and 11 days were calculated for PCE, TCE, cDCE, and VC, respectively (Table 7). These results indicate that microbial populations present at the Site are capable of complete chlorinated ethene degradation under anaerobic conditions.

1,2-DCB was observed to decrease below the detection limit in the first replicate by Day 153 and in the second replicate by Day 217; a half-life of 19 days was calculated for the average of these results. A resulting increase in CB was also observed after the 1,2-DCB began to degrade and reached an average concentration of 50 mg/L by Day 217 from 12 mg/L on Day 0. CB was not observed to decrease in concentration over the incubation period and a half-life was not calculable. These results suggest that partial dechlorination of the dichlorobenzene compounds to CB is possible with the addition of sulfate and lactate, but complete dechlorination of CB did not occur under these conditions. 2-CT, ethyl benzene, and *o*-xylene remained relatively stable over the incubation period and had high half-lives of 345, 536 and 587 days, respectively. However, substantial degradation of toluene was observed, with decreases from 35 mg/L at Day 28 to 0.47 mg/L at Day 217; a half-life of 30 days was calculated. These results indicate that partial degradation of the chlorinated aromatic and TEX compounds, and complete dechlorination of the chlorinated ethenes to ethene, can be completed by microbial populations native to the Site under anaerobic conditions with the addition of sulfate and lactate.

3.5 Nutrisulfate[®] and Nutrimens[®] Amended Microcosms

In the Nutrisulfate[®] and Nutrimens[®] amended treatment sulfate reduction was not observed until after the addition of Nutrimens[®] was started on Day 64 (Table 3). This suggests that bacteria intrinsic to the site were not capable of using the TEX compounds or chlorinated aromatics as electron donors for sulfate reduction. After the weekly additions of Nutrimens[®], sulfate was partially reduced in the first replicate, with concentrations of sulfate decreasing from 414 mg/L on Day 56 to 172 mg/L on Day 217, while sulfate reduction was not observed in the second replicate. Dissolved Fe was observed to decrease in concentration over the lifetime of the study; dissolved Mn increased slightly (Table 6). This suggests that the metals were reduced to their more soluble forms (Fe^{2+} and Mn^{2+}) and Fe was likely then precipitated out of solution with the sulfide produced from sulfate reduction. Methane was not observed to increase over the incubation period. These results indicate that sufficiently reducing conditions for dechlorination were achieved in these microcosms, but strongly reducing methanogenic conditions were not achieved.

Lactate was detected at an average concentration of 25 mg/L on Day 0, but decreased in concentration to below the detection limit by Day 14 and did not increase in concentration over the duration of the study (Table 4). The increase in lactate was from the Nutrisulfate[®] amendment. After the regular additions of Nutrimens[®] were started on Day 64 the acetate concentration increased continually from an average concentration of 186 mg/L on Day 96 to 291 mg/L on Day 217. These results suggest that the lactate and other fermentable products in the Nutrimens[®] and Nutrisulfate[®] were fermented to acetate after each addition.

The pH of the Nutrimens[®] and Nutrisulfate[®] amended microcosms initially remained relatively stable between Day 0 and Day 97 (Table 5). The pH of the microcosms then increased to an average of 6.66 on Day 125. After which, the pH remained relatively stable for the remainder of the incubation period. The increase in pH by Day 125 is likely a result of the acid-consuming sulfate reduction reactions competing with the acid-generating fermentation reactions. The slower reduction of sulfate that was observed in these microcosms accounts for the more gradual increase in pH over time, especially when compared to the pH increases observed in the lactate and sulfate amended treatment.

Similar to the controls and lactate/sulfate amended microcosms, the chlorinated ethenes, chlorinated aromatics and TEX concentrations were observed to increase from Day 0 to Day 28.

Complete dechlorination of the chlorinated ethenes to ethene was observed in the first replicate of the Nutrisulfate[®] and Nutrimens[®] amended microcosms by Day 153 (Table 2 and Figure 4A). Half-lives for the first replicate were calculated to be 3.9 days, 4.3 days, 23 days, and 25 days for PCE, TCE, cDCE, and VC, respectively (Table 7).

Partial dechlorination of 1,2-DCB to CB was observed in the first replicate of the Nutrisulfate and Nutrimens amended microcosms. 1,2-DCB decreased in concentration from 43 mg/L on Day 28 to 21 mg/L on Day 217. As a result, CB was observed to increase slightly in concentration from 17 mg/L on Day 28 to 22 mg/L on Day 186. A half-life for the 1,2-DCB degradation was calculated to be 179 Days. Toluene was also observed to degrade over the incubation period from 31 mg/L on Day 14 to 0.31 mg/L on Day 97, after which it remained stable. Complete toluene degradation was not observed over the incubation period, but a half-life of 36 days was calculated for the first replicate. 2-CT, ethyl benzene, and o-xylene were not observed to decrease substantially over the incubation period. Half-lives for these compounds were calculated and found to be 304, 297, and 377 days for 2-CT, ethyl benzene, and o-xylene. These results indicate that partial degradation of the aromatic and TEX compounds, and complete dechlorination of the chlorinated ethenes to ethene, can be completed by microbial populations native to the Site under anaerobic conditions with the addition of Nutrimens[®] and Nutrisulfate[®].

In the second replicate only partial dechlorination of PCE to cDCE was observed by Day 97, after which it remained stable with respect to cDCE until Day 217 (Figure 4B). Half-lives for the PCE and TCE degradation were calculated to be 3.2 and 4.2 days, respectively. A half-life of 487 days was calculated for cDCE and a half-life for VC was not calculated as VC degradation was not observed. Given that both of the lactate and sulfate amended replicates and one of the Nutrisulfate[®] and Nutrimens[®] amended replicates were capable of degrading PCE to ethene, the second replicate of this treatment may be considered an outlier.

The second replicate also showed less activity related to the chlorinated aromatic and TEX compounds. Unlike the first replicate, 1,2-DCB and toluene degradation was not observed. Half-lives for 1,2-DCB and toluene were calculated and found to be 373 and 465 days, respectively. The remaining aromatic compounds remained relatively stable over the incubation period. Half-lives of 399, 328, 314, and 502 days were calculated for 2-CT, ethyl benzene, o-xylene, and CB,

respectively. As noted above, sulfate reduction was not observed in the second replicate, indicating that sufficiently reducing conditions were not achieved to promote complete dechlorination or anaerobic aromatic degradation in this replicate.

3.6 Aerobic Treatments

In the original aerobic treatment, nitrate was present at low concentrations and was observed to decrease below the detection limit and sulfate was observed to increase over 62 days of incubation (Table 3). Dissolved Fe was observed to decrease in concentration over the aerobic incubation period (Table 6). This suggests that any Fe^{2+} , the more soluble iron cation, in solution was oxidized to Fe^{3+} , which may have then precipitated out of solution as iron oxides or hydroxides, especially given that the ORC[®]-A amended to the reactors produces hydroxide as part of its oxygen releasing reaction. These results combined with the frequent oxygen additions suggest that suitably aerobic conditions were maintained in the microcosms over the incubation period.

In both aerobic treatments, the pH was observed to decrease over the first 28 days of the study (Table 5). After that period, the pH was observed to increase, especially in the original aerobic microcosms, but the pH remained in the neutral range (pH 6.0 – 8.0). The increase in pH is likely a result of the ORC[®]-A addition, which releases oxygen by reacting calcium hydroxides with water. As a by-product of this process, hydroxide is also created, which increases the pH. These results suggest that ORC[®]-A can maintain the Site materials at a pH suitable for biological activity to occur.

All compounds were observed to be degraded below the detection limits over the incubation periods of both aerobic treatments (Table 2 and Figures 5 and 6). The original aerobic treatment was observed to have nearly degraded all of the TEX and aromatic compounds in the microcosms by Day 7. Before the addition of ORC[®]-A to the original aerobic treatment, the microcosms had been exposed to atmospheric oxygen immediately after construction and then incubated on the bench top for 7 days prior to spiking and 8 days prior to time zero analysis. The initial oxygen exposure may have caused the chlorinated ethenes, chlorinated aromatics and TEX compounds to begin degrading more rapidly than expected. To verify these results, the microcosms were spiked with all of the target compounds to their respective target concentrations (as discussed in Section 2.1) again on Day 12 of the study. The compounds (including the chlorinated ethenes), were completely degraded a second time by Day 62 of the study. The half-lives calculated for the original aerobic microcosms are provided in Table 7 and were determined using the concentrations measured after the second target compound spiking event.

After the original aerobic treatment was observed to have completely degraded the target compounds in 7 days, a second aerobic treatment was constructed to verify the results along with the second target compound spiking event. The new aerobic microcosms were constructed under anaerobic conditions to remove any oxygen that may have been present in the microcosms before the study began and prevent any compound degradation before the time zero analysis could be completed. After 43 days of incubation, this treatment was also observed

to undergo complete degradation of all target compounds. In general, the half-lives from the second aerobic treatment were longer than those in the first aerobic treatment (Table 7). This was likely a result of the second treatment being prepared anaerobically and then made aerobic, as opposed to the first treatment, which was already aerobic when it was spiked with the target compounds. The results from both the first and second aerobic treatment suggest that complete degradation of the target compounds can be achieved by aerobic microbial populations present at the Site.

4. CONCLUSIONS

The laboratory biotreatability study results suggest the following conclusions:

1. Lactate and Nutrimens[®] promoted the appropriate geochemical conditions (i.e., sulfate reducing conditions) for bioremediation of the chlorinated ethenes, 1,2-DCB, and toluene.
2. Intrinsic microorganisms present in the Site materials are capable of promoting complete dechlorination of the chlorinated ethenes to ethene and partial degradation of 1,2-DCB and toluene under anaerobic conditions with the addition of a sulfate substrate and electron donor.
3. The addition of sulfate or Nutrisulfate[®] did not promote the appropriate geochemical conditions for bioremediation of TEX, CB, or 2-CT.
4. ORC[®]-A and multiple oxygen gas additions per week promoted the appropriate geochemical conditions (i.e., aerobic conditions) for bioremediation of chlorinated ethenes, chlorinated aromatics and TEX compounds.
5. Intrinsic microorganisms present in the Site materials are capable of promoting complete degradation of the chlorinated ethenes, chlorinated aromatics, and TEX compounds under aerobic conditions with the addition of an oxygen source.

The results of this study indicate that aerobic biodegradation using ORC[®]-A and oxygen gas additions was the most effective remedial approach to reduce all compound concentrations present in the Site materials.

5. REFERENCES

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TABLES

TABLE 1: SUMMARY OF MICROCOSM TREATMENTS AND AMENDMENTS
Cranscon, Rhode Island

SiREM

Treatment/Control	Assigned bottle Number	Number of Microcosms	Geologic Material (g)	Groundwater (mL)	Headspace (mL)	Sodium Azide	Mercuric Chloride	Rezaurin	VOCs	Lactate	Sulfate	Nutrisulfate®	Nutrimens®	ORC-A and Oxygen Addition
Anaerobic Sterile Control	1 to 2	2 (2)	60	200	50	Amended with 0.5 mL of a 5% solution on Day -8.	Amended with 2.8 mL of a 2.7% solution on Day -8.	Amended first replicate with 100 µL of a 1000 mg/L resazurin solution on Day -8.	Spiked with 14 µL of a neat VOC cocktail to reach target concentrations of 0.4 mg/L for o-xylene; 0.5 mg/L for TCE, cDCE, and EB; 10 mg/L for CB and 2-CT; 20 mg/L for toluene; and 30 mg/L for 1,2-DCB on Day -1.	NA	NA	NA	NA	NA
Lactate and Sulfate Amended	3 to 4	2 (2)	60	200	50	NA	NA	Amended first replicate with 100 µL of a 1000 mg/L resazurin solution on Day -8.	Spiked with 14 µL of a neat VOC cocktail to reach target concentrations of 0.4 mg/L for o-xylene; 0.5 mg/L for TCE, cDCE, and EB; 10 mg/L for CB and 2-CT; 20 mg/L for toluene; and 30 mg/L for 1,2-DCB on Day -1.	Amended with 41 µL of a 6% sodium lactate solution to a target concentration of 12.5 mg/L lactate on a weekly basis starting on Day 64 and ending Day 183.	Amended with 0.5 mL of a 325 g/L MgSO ₄ solution to a target concentration of 330 mg/L sulfate on Day 0.	NA	NA	NA
Nutrisulfate® and Nutrimens® Amended	5 to 6	2 (2)	60	200	50	NA	NA	Amended first replicate with 100 µL of a 1000 mg/L resazurin solution on Day -8.	Spiked with 14 µL of a neat VOC cocktail to reach target concentrations of 0.4 mg/L for o-xylene; 0.5 mg/L for TCE, cDCE, and EB; 10 mg/L for CB and 2-CT; 20 mg/L for toluene; and 30 mg/L for 1,2-DCB on Day -1.	NA	NA	Amended with 768 µL of Nutrisulfate® to a target concentration of 500 mg/L sulfate on Day 0.	Amended with 80 µL of a 10% Nutrimens solution to a target concentration of 12.5 mg/L lactate on a weekly basis starting on Day 64.	NA
First Aerobic ORC ⁺ -A Amended	7 to 8	2 (2)	60	200	50	NA	NA	Amended first replicate with 100 µL of a 1000 mg/L resazurin solution on Day -8.	Spiked with 14 µL of a neat VOC cocktail to reach target concentrations of 0.4 mg/L for o-xylene; 0.5 mg/L for TCE, cDCE, and EB; 10 mg/L for CB and 2-CT; 20 mg/L for toluene; and 30 mg/L for 1,2-DCB on Day -1 and Day 13.	NA	NA	NA	NA	Amended with 0.01 g of ORC-A on Day 0. Amended with 5 mL of oxygen gas three times a week starting on Day 0.
Second Aerobic ORC ⁺ -A Amended	9 to 10	2	60	200	50	NA	NA	Amended first replicate with 100 µL of a 1000 mg/L resazurin solution on Day -1.	Spiked with 14 µL of a neat VOC cocktail to reach target concentrations of 0.4 mg/L for o-xylene; 0.5 mg/L for TCE, cDCE, and EB; 10 mg/L for CB and 2-CT; 20 mg/L for toluene; and 30 mg/L for 1,2-DCB on Day -1.	NA	NA	NA	NA	Amended with 0.01 g of ORC-A on Day 0.1. Amended with 5 mL of oxygen gas three times a week starting on Day 0.1.

Notes:
% - percent
µL - microliters
cDCE - cis-1,2-dichloroethene
CB - chlorobenzene
2-CT - 2-chlorotoluene
1,2-DCB - 1,2-dichlorobenzene
EB - ethyl benzene
g - grams
g/L - grams per liter
MgSO₄ - magnesium sulfate
mg/L - milligrams per liter
mL - milliliters
NA - not applicable
ORC⁺-A - oxygen release compound - advanced
TCE - trichloroethene
VOC - volatile organic compound

TABLE 2: SUMMARY OF MICROCOSM cVOC, BTX AND DHG RESULTS
Cranston, Rhode Island

SIREM

Treatment	Date	Day	Replicate	Chlorinated Ethenes and Ethene					Ethane and Methane		Chlorinated Aromatics and BTEX									Comment		
				PCE	TCE	cDCE	VC	Ethene	Total Ethenes	Ethane	Methane	1,2-DCB	1,4-DCB	1,3-DCB	CB	2-CT	Benzene	Toluene	EB		o-Xylene	
				mg/L	mg/L	mg/L	mg/L	mg/L	mmol/bottle	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L		mg/L	
Anaerobic Sterile Control	17-Sep-14	-8																				Amended first replicate with 100 µL of resazurin.
																						Poisoned with mercuric chloride and sodium azide.
	24-Sep-14	-1																				Spiked with TCE and cDCE to target concentrations of 0.5 mg/L each.
																						Spiked with 1,2-DCB, chlorobenzene, and 2-CT to target concentrations of 30 mg/L, 10 mg/L, and 10 mg/L, respectively.
																						Spiked with toluene, ethyl benzene, and o-xylene to target concentrations of 20 mg/L, 0.5 mg/L, and 0.4 mg/L, respectively.
	25-Sep-14	0	ANSC-1	0.49	0.47	0.60	<0.10	<0.10	--	<0.10	0.20	13	<0.30	<0.10	6.8	2.0	<0.10	10	0.12	0.15		
			ANSC-2	0.16	0.28	0.61	<0.10	<0.10	--	<0.10	0.26	16	<0.30	<0.10	7.8	2.9	<0.10	12	0.16	0.19		
			Average Concentration (mg/L)	0.32	0.37	0.61	ND	ND	--	ND	0.23	15	ND	ND	7.3	2.4	ND	11	0.14	0.17		
			Standard Deviation (mmoles)	3.1E-04	2.2E-04	1.8E-05	0.0E+00	0.0E+00	--	0.0E+00	1.9E-03	2.8E-03	0.0E+00	0.0E+00	1.4E-03	1.0E-03	0.0E+00	2.3E-03	5.1E-05	6.3E-05		
			Average Total mmoles	0.00042	0.00060	0.0013	ND	ND	2.3E-03	ND	0.011	0.020	ND	0.013	0.0039	ND	0.024	0.00027	0.00032			
	09-Oct-14	14	ANSC-1	0.81	1.0	0.82	<0.10	<0.10	--	<0.10	0.22	35	<0.30	<0.10	14	8.6	<0.10	29	0.53	0.60		
			ANSC-2	0.23	0.56	0.86	<0.10	<0.10	--	<0.10	0.25	36	<0.30	<0.10	15	9.3	<0.10	31	0.55	0.65		
			Average Concentration (mg/L)	0.52	0.78	0.84	ND	ND	--	ND	0.24	35	ND	ND	15	9.0	ND	30	0.54	0.62		
			Standard Deviation (mmoles)	5.4E-04	5.2E-04	5.4E-05	0.0E+00	0.0E+00	--	0.0E+00	1.1E-03	1.3E-03	0.0E+00	0.0E+00	1.6E-03	7.8E-04	0.0E+00	3.7E-03	3.0E-05	6.1E-05		
			Average Total mmoles	0.00069	0.0013	0.0018	ND	ND	3.8E-03	ND	0.011	0.048	ND	0.027	0.014	ND	0.067	0.0010	0.0012			
	23-Oct-14	28	ANSC-1	0.93	1.2	0.82	<0.10	<0.10	--	<0.10	0.20	33	<0.30	<0.10	14	8.2	<0.10	27	0.47	0.57		
			ANSC-2	0.22	0.61	0.92	<0.10	<0.10	--	<0.10	0.25	42	<0.30	<0.10	16	11	<0.10	33	0.61	0.73		
			Average Concentration (mg/L)	0.58	0.92	0.87	ND	ND	--	ND	0.23	38	ND	ND	15	9.5	ND	30	0.54	0.65		
			Standard Deviation (mmoles)	6.6E-04	7.0E-04	1.4E-04	0.0E+00	0.0E+00	--	0.0E+00	1.5E-03	8.5E-03	0.0E+00	0.0E+00	3.6E-03	3.0E-03	0.0E+00	9.3E-03	1.9E-04	2.2E-04		
			Average Total mmoles	0.00076	0.0015	0.0018	ND	ND	4.1E-03	ND	0.011	0.052	ND	0.027	0.015	ND	0.067	0.0010	0.0012			
	20-Nov-14	56	ANSC-1	1.1	1.6	0.80	<0.10	<0.10	--	<0.10	0.24	32	<0.30	<0.10	14	8.2	<0.10	28	0.49	0.51		
			ANSC-2	0.20	0.57	0.84	<0.10	<0.10	--	<0.10	0.30	38	<0.30	<0.10	15	10	<0.10	31	0.59	0.71		
			Average Concentration (mg/L)	0.67	1.1	0.82	ND	ND	--	ND	0.27	35	ND	ND	15	9.1	ND	29	0.54	0.61		
			Standard Deviation (mmoles)	8.7E-04	1.2E-03	5.7E-05	0.0E+00	0.0E+00	--	0.0E+00	1.9E-03	6.5E-03	0.0E+00	0.0E+00	2.0E-03	2.1E-03	0.0E+00	4.3E-03	1.4E-04	2.8E-04		
			Average Total mmoles	0.00088	0.0018	0.0018	ND	ND	4.5E-03	ND	0.012	0.048	ND	0.026	0.015	ND	0.066	0.0010	0.0012			
	25-Feb-15	153	ANSC-1	0.95	1.8	0.64	<0.10	<0.10	--	<0.10	0.34	27	<0.30	<0.10	11	6.1	<0.10	22	0.39	0.44		
			ANSC-2	<0.10	0.35	0.61	<0.10	<0.10	--	<0.10	0.38	30	<0.30	<0.10	11	7.5	<0.10	23	0.45	0.49		
		Average Concentration (mg/L)	0.48	1.1	0.62	ND	ND	--	ND	0.36	28	ND	ND	11	6.8	ND	23	0.42	0.46			
		Standard Deviation (mmoles)	8.9E-04	1.7E-03	3.6E-05	0.0E+00	0.0E+00	--	0.0E+00	1.5E-03	2.7E-03	0.0E+00	0.0E+00	8.1E-04	1.6E-03	0.0E+00	2.4E-03	8.1E-05	5.8E-05			
		Average Total mmoles	0.00063	0.0018	0.0013	ND	ND	3.7E-03	ND	0.017	0.039	ND	ND	0.020	0.011	ND	0.050	0.00082	0.00089			
30-Apr-15	217	ANSC-1	0.49	2.1	0.66	<0.10	<0.10	--	<0.10	0.30	24	<0.30	<0.10	10	5.4	<0.10	21	0.30	0.49			
		ANSC-2	<0.10	0.48	0.72	<0.10	<0.10	--	<0.10	0.36	32	<0.30	<0.10	13	8.4	<0.10	26	0.48	0.60			
		Average Concentration (mg/L)	0.24	1.3	0.69	ND	ND	--	ND	0.33	28	ND	ND	12	6.9	ND	24	0.39	0.54			
		Standard Deviation (mmoles)	4.5E-04	1.8E-03	8.7E-05	0.0E+00	0.0E+00	--	0.0E+00	2.1E-03	8.4E-03	0.0E+00	0.0E+00	3.5E-03	3.4E-03	0.0E+00	8.4E-03	2.4E-04	1.4E-04			
		Average Total mmoles	0.00032	0.0021	0.0015	ND	ND	3.9E-03	ND	0.015	0.039	ND	0.021	0.011	ND	0.053	0.00075	0.0010				
Lactate and Sulfate Amended	17-Sep-14	-8																				Amended first replicate with 100 µL of resazurin.
																						Spiked with TCE and cDCE to target concentrations of 0.5 mg/L each.
	24-Sep-14	-1																				Spiked with toluene, ethyl benzene, and o-xylene to target concentrations of 20 mg/L, 0.5 mg/L, and 0.4 mg/L, respectively.
																						Spiked with 1,2-DCB, chlorobenzene, and 2-CT to target concentrations of 30 mg/L, 10 mg/L, and 10 mg/L, respectively.
																						Amended with magnesium sulfate to a target concentration of 330 mg/L sulfate.
	25-Sep-14	0	LAC/SO4-1	0.60	0.50	0.84	<0.10	<0.10	--	<0.10	0.33	22	<0.30	<0.10	12	4.3	<0.10	21	0.27	0.34		
			LAC/SO4-2	0.78	0.46	0.80	<0.10	<0.10	--	<0.10	0.42	27	<0.30	<0.10	12	5.3	<0.10	21	0.30	0.37		
			Average Concentration (mg/L)	0.69	0.48	0.82	ND	ND	--	ND	0.37	24	ND	ND	12	4.8	ND	21	0.29	0.35		
			Standard Deviation (mmoles)	1.6E-04	4.1E-05	6.3E-05	0.0E+00	0.0E+00	--	0.0E+00	3.1E-03	5.0E-03	0.0E+00	0.0E+00	9.9E-05	1.1E-03	0.0E+00	3.2E-05	4.0E-05	2.8E-05		
			Average Total mmoles	0.00091	0.00077	0.0018	ND	ND	3.5E-03	ND	0.017	0.033	ND	ND	0.021	0.0077	ND	0.047	0.00056	0.00068		
	09-Oct-14	14	LAC/SO4-1	<0.10	1.4	0.93	<0.10	<0.10	--	<0.10	0.32	41	<0.30	<0.10	16	9.9	<0.10	30	0.55	0.65		
			LAC/SO4-2	0.25	0.76	1.1	<0.10	<0.10	--	<0.10	0.40	38	<0.30	<0.10	14	8.6	<0.10	25	0.48	0.56		
			Average Concentration (mg/L)	0.13	1.1	1.0	ND	ND	--	ND	0.36	40	ND	ND	15	9.2	ND	27	0.52	0.60		
			Standard Deviation (mmoles)	2.3E-04	7.2E-04	2.0E-04	0.0E+00	0.0E+00	--	0.0E+00	2.7E-03	2.9E-03	0.0E+00	0.0E+00	2.5E-03	1.4E-03	0.0E+00	7.3E-03	1.0E-04	1.3E-04		
			Average Total mmoles	0.00016	0.0017	0.0021	ND	ND	4.0E-03	ND	0.017	0.054	ND	0.027	0.015	ND	0.061	0.0010	0.0012			
	23-Oct-14	28	LAC/SO4-1	<0.10	0.98	1.7	<0.10	<0.10	--	<0.10	0.34	50	<0.30	<0.10	19	12	<0.10	35	0.65	0.78		
			LAC/SO4-2	<0.10	<0.10	2.5	<0.10	<0.10	--	<0.10	0.47	50	<0.30	<0.10	19	12	<0.10	34	0.64	0.74		
			Average Concentration (mg/L)	ND	0.49	2.1	ND	ND	--	ND	0.40	50	ND	ND	19	12	ND	35	0.64	0.76		
			Standard Deviation (mmoles)	0.0E+00	1.1E-03	1.3E-03	0.0E+00	0.0E+00	--	0.0E+00	4.2E-03	2.0E-04	0.0E+00	0.0E+00	5.1E-04	9.7E-05	0.0E+00	1.8E-03	1.9E-05	5.6E-05		
			Average Total mmoles	ND	0.00078	0.0045	ND	ND	5.3E-03	ND	0.019	0.069	ND	0.034								

TABLE 2: SUMMARY OF MICROCOSM cVOC, BTEX AND DHG RESULTS
Cranston, Rhode Island

SIREM

Treatment	Date	Day	Replicate	Chlorinated Ethenes and Ethene					Ethane and Methane		Chlorinated Aromatics and BTEX										Comment	
				PCE	TCE	cDCE	VC	Ethene	Total Ethenes	Ethane	Methane	1,2-DCB	1,4-DCB	1,3-DCB	CB	2-CT	Benzene	Toluene	EB	o-Xylene		
Lactate and Sulfate Amended Continued	28-Jan-15	125	LAC/SO4-1	<0.10	<0.10	1.7	<0.10	<0.10	--	<0.10	0.78	10	<0.30	<0.10	34	7.7	<0.10	1.4	0.41	0.55		
			LAC/SO4-2	<0.10	<0.10	1.6	<0.10	<0.10	--	<0.10	0.60	35	<0.30	<0.10	13	7.8	<0.10	2.6	0.37	0.52		
			Average Concentration (mg/L)	ND	ND	1.7	ND	ND	--	ND	0.69	23	ND	ND	24	7.8	ND	2.0	0.39	0.53		
			Standard Deviation (mmoles)	0.0E+00	0.0E+00	4.8E-05	0.0E+00	0.0E+00	--	0.0E+00	5.6E-03	2.5E-02	0.0E+00	0.0E+00	2.7E-02	1.4E-04	0.0E+00	1.9E-03	6.2E-05	3.7E-05		
				Average Total mmoles	ND	ND	0.0035	ND	ND	3.5E-03	ND	0.032	0.031	ND	ND	0.043	0.012	ND	0.0046	0.00075	0.0010	
	06-Feb-15	134																		Amended with lactate to a target concentration of 12.5 mg/L.		
	13-Feb-15	141																		Amended with lactate to a target concentration of 12.5 mg/L.		
	20-Feb-15	148																		Amended with lactate to a target concentration of 12.5 mg/L.		
	25-Feb-15	153	LAC/SO4-1	<0.10	<0.10	1.1	0.39	<0.10	--	<0.10	0.46	5.7	<0.30	<0.10	40	7.8	<0.10	0.22	0.46	0.53		
			LAC/SO4-2	<0.10	<0.10	1.2	0.47	<0.10	--	<0.10	0.41	<0.50	<0.30	<0.10	48	8.2	<0.10	0.27	0.50	0.55		
			Average Concentration (mg/L)	ND	ND	1.2	0.43	ND	--	ND	0.44	2.9	ND	ND	44	8.0	ND	0.24	0.48	0.54		
			Standard Deviation (mmoles)	0.0E+00	0.0E+00	6.0E-05	1.9E-04	0.0E+00	--	0.0E+00	1.7E-03	5.6E-03	0.0E+00	0.0E+00	1.0E-02	3.8E-04	0.0E+00	7.5E-05	6.0E-05	2.7E-05		
			Average Total mmoles	ND	ND	0.0025	0.0015	ND	4.0E-03	ND	0.020	0.0039	ND	ND	0.079	0.013	ND	0.00054	0.00094	0.0010		
	28-Feb-15	156																		Amended with lactate to a target concentration of 12.5 mg/L.		
	06-Mar-15	162																		Amended with lactate to a target concentration of 12.5 mg/L.		
	13-Mar-15	169																		Amended with lactate to a target concentration of 12.5 mg/L.		
	20-Mar-15	176																		Amended with lactate to a target concentration of 12.5 mg/L.		
	27-Mar-15	183																		Amended with lactate to a target concentration of 12.5 mg/L.		
	30-Mar-15	186	LAC/SO4-1	<0.10	<0.10	<0.10	<0.10	0.23	--	<0.10	0.40	4.1	<0.30	<0.10	47	7.8	<0.10	0.61	0.38	0.50		
			LAC/SO4-2	<0.10	<0.10	<0.10	<0.10	0.18	--	<0.10	0.36	<0.50	<0.30	<0.10	47	7.9	<0.10	0.36	0.48	0.52		
Average Concentration (mg/L)			ND	ND	ND	ND	0.21	--	ND	0.38	2.0	ND	ND	47	7.8	ND	0.49	0.43	0.51			
Standard Deviation (mmoles)			0.0E+00	0.0E+00	0.0E+00	0.0E+00	4.6E-04	--	0.0E+00	1.5E-03	4.0E-03	0.0E+00	0.0E+00	9.6E-05	9.2E-05	0.0E+00	3.9E-04	1.4E-04	2.0E-05			
		Average Total mmoles	ND	ND	ND	ND	0.0027	2.7E-03	ND	0.018	0.0028	ND	ND	0.085	0.013	ND	0.0011	0.00084	0.0010			
30-Apr-15	217	LAC/SO4-1	<0.10	<0.10	<0.10	<0.10	<0.10	--	0.15	0.46	<0.50	<0.30	<0.10	49	7.9	0.10	0.77	0.48	0.64			
		LAC/SO4-2	<0.10	<0.10	<0.10	<0.10	0.22	--	<0.10	0.37	<0.50	<0.30	<0.10	51	8.7	<0.10	0.17	0.50	0.58			
		Average Concentration (mg/L)	ND	ND	ND	ND	0.11	--	0.073	0.42	ND	ND	ND	50	8.3	0.052	0.47	0.49	0.61			
		Standard Deviation (mmoles)	0.0E+00	0.0E+00	0.0E+00	0.0E+00	2.1E-03	--	2.0E-03	2.9E-03	0.0E+00	0.0E+00	0.0E+00	2.4E-03	8.8E-04	1.9E-04	9.5E-04	2.8E-05	8.1E-05			
		Average Total mmoles	ND	ND	ND	ND	0.0015	1.5E-03	0.0014	0.019	ND	ND	ND	0.090	0.013	0.00014	0.0010	0.00094	0.0012			
Nutrisulfate® and Nutrimens® Amended	17-Sep-14	-8																		Amended first replicate with 100 µL of resazurin.		
	24-Sep-14	-1																		Spiked with 1,2-DCB, chlorobenzene, and 2-CT to target concentrations of 30 mg/L, 10 mg/L, and 10 mg/L, respectively.		
																				Spiked with TCE and cDCE to target concentrations of 0.5 mg/L each.		
																				Spiked with toluene, ethyl benzene, and o-xylene to target concentrations of 20 mg/L, 0.5 mg/L, and 0.4 mg/L, respectively.		
	25-Sep-14	0																		Amended with 768 µL of Nutrisulfate® to a target concentration of 500 mg/L sulfate.		
			NuSO4-1	0.58	0.47	0.87	<0.10	<0.10	--	<0.10	0.36	26	<0.30	<0.10	12	5.3	<0.10	22	0.31	0.38		
			NuSO4-2	0.96	0.51	0.96	<0.10	<0.10	--	<0.10	0.45	30	<0.30	<0.10	13	5.5	<0.10	23	0.3	0.38		
			Average Concentration (mg/L)	0.77	0.49	0.92	ND	ND	--	ND	0.41	28	ND	ND	12	5.4	ND	22	0.31	0.38		
		Standard Deviation (mmoles)	3.6E-04	3.9E-05	1.3E-04	0.0E+00	0.0E+00	--	0.0E+00	2.9E-03	3.7E-03	0.0E+00	0.0E+00	1.0E-03	2.1E-04	0.0E+00	7.5E-04	1.4E-05	2.4E-07			
		Average Total mmoles	0.0010	0.00078	0.0020	ND	ND	3.8E-03	ND	0.019	0.038	ND	ND	0.022	0.0086	ND	0.050	0.00060	0.00073			
	09-Oct-14	14	NuSO4-1	<0.10	<0.10	2.0	<0.10	<0.10	--	<0.10	0.35	41	<0.30	<0.10	16	9.7	<0.10	31	0.57	0.66		
			NuSO4-2	<0.10	<0.10	2.1	<0.10	<0.10	--	<0.10	0.52	35	<0.30	<0.10	14	8.1	<0.10	27	0.48	0.56		
			Average Concentration (mg/L)	ND	ND	2.0	ND	ND	--	ND	0.44	38	ND	ND	15	8.9	ND	29	0.52	0.61		
			Standard Deviation (mmoles)	0.0E+00	0.0E+00	2.0E-04	0.0E+00	0.0E+00	--	0.0E+00	5.5E-03	5.6E-03	0.0E+00	0.0E+00	2.6E-03	1.8E-03	0.0E+00	6.4E-03	1.2E-04	1.3E-04		
		Average Total mmoles	ND	ND	0.0044	ND	ND	4.4E-03	ND	0.020	0.052	ND	ND	0.028	0.014	ND	0.064	0.0010	0.0012			
	23-Oct-14	28	NuSO4-1	<0.10	<0.10	2.0	<0.10	<0.10	--	<0.10	0.37	43	<0.30	<0.10	17	10	<0.10	31	0.58	0.71		
			NuSO4-2	<0.10	<0.10	2.4	<0.10	<0.10	--	<0.10	0.45	43	<0.30	<0.10	16	9.4	<0.10	30	0.53	0.65		
			Average Concentration (mg/L)	ND	ND	2.2	ND	ND	--	ND	0.41	43	ND	ND	17	9.9	ND	31	0.56	0.68		
			Standard Deviation (mmoles)	0.0E+00	0.0E+00	6.0E-04	0.0E+00	0.0E+00	--	0.0E+00	2.6E-03	9.6E-05	0.0E+00	0.0E+00	6.2E-04	1.1E-03	0.0E+00	2.2E-03	7.0E-05	8.4E-05		
		Average Total mmoles	ND	ND	0.0047	ND	ND	4.7E-03	ND	0.019	0.059	ND	ND	0.030	0.016	ND	0.068	0.0011	0.0013			
20-Nov-14	56	NuSO4-1	<0.10	<0.10	1.8	<0.10	<0.10	--	<0.10	0.35	40	<0.30	<0.10	16	9.2	<0.10	27	0.53	0.62			
		NuSO4-2	<0.10	0.17	2.3	<0.10	<0.10	--	<0.10	0.45	36	<0.30	<0.10	15	7.8	<0.10	27	0.44	0.52			
		Average Concentration (mg/L)	ND	0.083	2.0	ND	ND	--	ND	0.40	38	ND	ND	16	8.5	ND	27	0.48	0.57			
		Standard Deviation (mmoles)	0.0E+00	1.9E-04	6.4E-04	0.0E+00	0.0E+00	--	0.0E+00	3.2E-03	3.4E-03	0.0E+00	0.0E+00	1.8E-03	1.5E-03	0.0E+00	3.8E-04	1.3E-04	1.3E-04			
	Average Total mmoles	ND	0.00013	0.0043	ND	ND	4.4E-03	ND	0.019	0.052	ND	ND	0.028	0.014	ND	0.060	0.00094	0.0011				
28-Nov-14	64																		Amended with nutrimens to a target concentration of 12.5 mg/L as lactate.			
05-Dec-14	71																		Amended with nutrimens to a target concentration of 12.5 mg/L as lactate.			
15-Dec-14	81																		Amended with nutrimens to a target concentration of 12.5 mg/L as lactate.			
19-Dec-14	85																		Amended with nutrimens to a target concentration of 12.5 mg/L as lactate.			
31-Dec-14	97	NuSO4-1	<0.10	<0.10	1.4	0.24	<0.10	--	<0.10	0.33	30	<0.30	<0.10	19	7.7	<0.10	0.31	0.47	0.47			
		NuSO4-2	<0.10	<0.10	2.2	<0.10	<0.10	--	<0.10	0.45	39	<0.30	<0.10	16	8.6	<0.10	28	0.50	0.57			
		Average Concentration (mg/L)	ND	ND	1.8	0.12	ND	--	ND	0.39	34	ND	ND	17	8.1	ND	14	0.48	0.52			
		Standard Deviation (mmoles)	0.0E+00	0.0E+00	1.3E-03	5.9E-04	0.0E+00	--	0.0E+00	4.0E-03	9.1E-03	0.0E+00	0.0E+00	4.9E-03	9.5E-04	0.0E+00	4.4E-02	4.3E-05	1.3E-04			
	Average Total mmoles	ND	ND	0.0038	0.00042	ND	4.2E-03	ND	0.018	0.047	ND	ND	0.032	0.013	ND	0.032	0.00094	0.0010				
06-Jan-15	103																		Amended with nutrimens to a target concentration of 12.5 mg/L as lactate.			
09-Jan-15	106																		Amended with nutrimens to a target concentration of 12.5 mg/L as lactate.			
16-Jan-15	113																		Amended with nutrimens to a target concentration of 12.5 mg/L as lactate.			
23-Jan-15	120																		Amended with nutrimens to a target concentration of 12.5 mg/L as lactate.			
28-Jan-15	125	NuSO4-1	<0.10	<0.10	0.42	0.40	<0.10	--	<0.10	0.78	23	<0.30	<0.10	18	6.7	<0.10	0.36	0.36	0.47			
		NuSO4-2	<0.10	<0.10	1.8	<0.10	<0.10	--	<0.10	0.81	33	<0.30	<0.10	13	7.4	<0.10	24	0.39	0.50			
		Average Concentration (mg/L)	ND	ND	1.1	0.20	ND	--	ND	0.80	28	ND	ND	16	7.0	ND	12	0.38	0.49			
		Standard Deviation (mmoles)	0.0E+00	0.0E+00	2.1E-03	9.9E-04	0.0E+00	--	0.0E+00	8.1E-04	1.0E-02	0.0E+00	0.0E+00	7.2E-03	8.7E-04	0.0E+00	3.7E-02	3.2E-05	3.6E-05			
	Average Total mmoles	ND	ND	0.0024	0.00070	ND	3.1E-03	ND	0.037	0.038	ND	ND	0.028	0.011	ND	0.027	0.00073	0.00094				
06-Feb-15	134																		Amended with nutrimens to a target concentration of 12.5 mg/L as lactate.			
13-Feb-15	141																		Amended with nutrimens to a target concentration of 12.5 mg/L as lactate.			
20-Feb-15	148																		Amended with nutrimens to a target concentration of 12.5 mg/L as lactate.			

TABLE 2: SUMMARY OF MICROCOSM cVOC, BTEX AND DHG RESULTS
Cranston, Rhode Island

SIREM

Treatment	Date	Day	Replicate	Chlorinated Ethenes and Ethene						Ethane and Methane		Chlorinated Aromatics and BTEX										Comment
				PCE	TCE	cDCE	VC	Ethene	Total Ethenes	Ethane	Methane	1,2-DCB	1,4-DCB	1,3-DCB	CB	2-CT	Benzene	Toluene	EB	o-Xylene		
Nutrisulfate® and Nutrimens® Amended Continued	25-Feb-15	153	NuSO4-1	<0.10	<0.10	<0.10	<0.10	0.17	--	<0.10	0.48	25	<0.30	<0.10	21	7.7	<0.10	0.48	0.47	0.52		
			NuSO4-2	<0.10	<0.10	1.9	<0.10	<0.10	--	<0.10	0.54	35	<0.30	<0.10	13	7.7	<0.10	25	0.45	0.51		
			Average Concentration (mg/L)	ND	ND	0.96	ND	0.087	--	ND	0.51	30	ND	ND	17	7.7	ND	13	0.46	0.51		
			Standard Deviation (mmoles)	0.0E+00	0.0E+00	2.9E-03	0.0E+00	1.6E-03	--	0.0E+00	2.1E-03	9.3E-03	0.0E+00	0.0E+00	9.3E-03	4.3E-06	0.0E+00	3.8E-02	3.0E-05	5.4E-06		
				Average Total mmoles	ND	ND	0.0020	ND	0.0012	3.2E-03	ND	0.024	0.041	ND	ND	0.031	0.012	ND	0.028	0.00089	0.00099	
	28-Feb-15	156																			Amended with nutrimens to a target concentration of 12.5 mg/L as lactate.	
	06-Mar-15	162																			Amended with nutrimens to a target concentration of 12.5 mg/L as lactate.	
	13-Mar-15	169																			Amended with nutrimens to a target concentration of 12.5 mg/L as lactate.	
	20-Mar-15	176																			Amended with nutrimens to a target concentration of 12.5 mg/L as lactate.	
	27-Mar-15	183																			Amended with nutrimens to a target concentration of 12.5 mg/L as lactate.	
	30-Mar-15	186	NuSO4-1	<0.10	<0.10	<0.10	<0.10	0.17	--	<0.10	0.48	26	<0.30	<0.10	22	8.1	<0.10	0.84	0.45	0.55		
			NuSO4-2	<0.10	<0.10	2.1	<0.10	<0.10	--	<0.10	0.54	33	<0.30	<0.10	14	7.6	<0.10	26	0.45	0.53		
			Average Concentration (mg/L)	ND	ND	1.0	ND	0.087	--	ND	0.51	30	ND	ND	18	7.9	ND	14	0.45	0.54		
			Standard Deviation (mmoles)	0.0E+00	0.0E+00	3.1E-03	0.0E+00	1.6E-03	--	0.0E+00	2.0E-03	7.1E-03	0.0E+00	0.0E+00	9.7E-03	6.7E-04	0.0E+00	4.0E-02	5.0E-06	2.4E-05		
				Average Total mmoles	ND	ND	0.0022	ND	0.0011	3.3E-03	ND	0.024	0.040	ND	ND	0.033	0.013	ND	0.030	0.00088	0.0010	
	02-Apr-15	189																			Amended with nutrimens to a target concentration of 12.5 mg/L as lactate.	
	10-Apr-15	197																			Amended with nutrimens to a target concentration of 12.5 mg/L as lactate.	
	17-Apr-15	204																			Amended with nutrimens to a target concentration of 12.5 mg/L as lactate.	
	24-Apr-15	211																			Amended with nutrimens to a target concentration of 12.5 mg/L as lactate.	
	30-Apr-15	217	NuSO4-1	<0.10	<0.10	<0.10	<0.10	0.16	--	<0.10	0.51	21	<0.30	<0.10	19	6.8	<0.10	0.81	0.38	0.50		
			NuSO4-2	<0.10	<0.10	1.8	<0.10	<0.10	--	<0.10	0.55	30	<0.30	<0.10	13	6.8	<0.10	23	0.36	0.43		
			Average Concentration (mg/L)	ND	ND	0.92	ND	0.081	--	ND	0.53	25	ND	ND	16	6.8	ND	12	0.37	0.47		
			Standard Deviation (mmoles)	0.0E+00	0.0E+00	2.8E-03	0.0E+00	1.5E-03	--	0.0E+00	1.1E-03	9.3E-03	0.0E+00	0.0E+00	8.3E-03	3.4E-06	0.0E+00	3.4E-02	2.5E-05	1.0E-04		
				Average Total mmoles	ND	ND	0.0020	ND	0.0011	3.1E-03	ND	0.025	0.035	ND	ND	0.029	0.011	ND	0.026	0.00071	0.00090	
	Original Aerobic ORC®-A Amended	17-Sep-14	-8																			Amended first replicate with 100 µL of resazurin.
		24-Sep-14	-1																			Spiked with toluene, ethyl benzene, and o-xylene to target concentrations of 20 mg/L, 0.5 mg/L, and 0.4 mg/L, respectively.
																						Spiked with TCE and cDCE to target concentrations of 0.5 mg/L each.
																		Spiked with 1,2-DCB, chlorobenzene, and 2-CT to target concentrations of 30 mg/L, 10 mg/L, and 10 mg/L, respectively.				
25-Sep-14		0																			Amended with 0.01 g ORC®-A and began addition of oxygen gas three times a week.	
			AERO-1	1.2	0.12	0.15	<0.10	<0.10	--	<0.10	0.46	14	<0.30	<0.10	0.28	0.80	<0.10	<0.10	<0.10	<0.10		
			AERO-2	0.51	<0.10	<0.10	<0.10	<0.10	--	<0.10	0.21	<0.50	<0.30	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10		
			Average Concentration (mg/L)	0.85	0.062	0.073	ND	ND	--	ND	0.33	7.0	ND	ND	0.14	0.40	ND	ND	ND	ND		
				Standard Deviation (mmoles)	6.3E-04	1.4E-04	2.2E-04	0.0E+00	0.0E+00	--	0.0E+00	8.4E-03	1.4E-02	0.0E+00	3.5E-04	9.0E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00		
				Average Total mmoles	0.0011	0.000099	0.00015	ND	ND	1.3E-03	ND	0.016	0.0096	ND	ND	0.00025	0.00064	ND	ND	ND	ND	
02-Oct-14		7	AERO-1	0.79	0.21	0.2	<0.10	<0.10	--	<0.10	0.23	0.92	<0.30	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10		
			AERO-2	0.15	0.11	0.24	<0.10	<0.10	--	<0.10	0.21	<0.50	<0.30	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10		
			Average Concentration (mg/L)	0.47	0.16	0.22	ND	ND	--	ND	0.22	0.46	ND	ND	ND	ND	ND	ND	ND	ND		
			Standard Deviation (mmoles)	6.0E-04	1.1E-04	5.8E-05	0.0E+00	0.0E+00	--	0.0E+00	6.9E-04	8.9E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00		
				Average Total mmoles	0.00062	0.00025	0.00047	ND	ND	1.3E-03	ND	0.010	0.00063	ND	ND	ND	ND	ND	ND	ND	ND	
08-Oct-14		13																			Re-spiked all compounds to original target concentrations.	
			AERO-1	0.16	0.50	0.80	<0.10	<0.10	--	<0.10	0.19	7.7	<0.30	<0.10	5.6	2.8	<0.10	18	0.21	0.26		
			AERO-2	0.40	0.43	0.69	<0.10	<0.10	--	<0.10	0.20	6.6	<0.30	<0.10	4.4	2.0	<0.10	15	0.21	0.18		
			Average Concentration (mg/L)	0.28	0.46	0.75	ND	ND	--	ND	0.19	7.1	ND	ND	5.0	2.4	ND	16	0.21	0.22		
				Standard Deviation (mmoles)	2.2E-04	8.6E-05	1.6E-04	0.0E+00	0.0E+00	--	0.0E+00	2.1E-04	1.1E-03	0.0E+00	1.4E-03	9.2E-04	0.0E+00	3.9E-03	2.3E-06	1.1E-04		
				Average Total mmoles	0.00037	0.00074	0.0016	ND	ND	2.7E-03	ND	0.0090	0.0098	ND	ND	0.0039	0.036	0.00040	0.00042	0.00042		
17-Oct-14		22	AERO-1	0.40	0.43	0.61	<0.10	<0.10	--	<0.10	0.19	0.99	<0.30	<0.10	<0.10	0.31	<0.10	0.14	<0.10	<0.10		
			AERO-2	0.16	0.29	0.48	<0.10	<0.10	--	<0.10	0.18	1.5	<0.30	<0.10	<0.10	0.63	<0.10	<0.10	<0.10	0.15		
			Average Concentration (mg/L)	0.28	0.36	0.55	ND	ND	--	ND	0.19	1.2	ND	ND	ND	0.47	ND	0.068	ND	0.077		
			Standard Deviation (mmoles)	2.2E-04	1.6E-04	1.9E-04	0.0E+00	0.0E+00	--	0.0E+00	3.7E-04	4.5E-04	0.0E+00	0.0E+00	0.0E+00	3.7E-04	0.0E+00	2.1E-04	0.0E+00	2.1E-04		
				Average Total mmoles	0.00037	0.00057	0.0012	ND	ND	2.1E-03	ND	0.0087	0.0017	ND	ND	ND	0.00076	ND	0.00015	ND	0.00015	
23-Oct-14		28	AERO-1	0.31	0.29	0.37	<0.10	<0.10	--	<0.10	0.19	<0.50	<0.30	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10		
			AERO-2	0.11	0.12	0.18	<0.10	<0.10	--	<0.10	0.19	<0.50	<0.30	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10		
			Average Concentration (mg/L)	0.21	0.20	0.27	ND	ND	--	ND	0.19	ND	ND	ND	ND	ND	ND	ND	ND	ND		
			Standard Deviation (mmoles)	1.8E-04	1.9E-04	2.9E-04	0.0E+00	0.0E+00	--	0.0E+00	1.8E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00		
				Average Total mmoles	0.00028	0.00033	0.00058	ND	ND	1.2E-03	ND	0.0089	ND	ND	ND	ND	ND	ND	ND	ND		
04-Nov-14		40	AERO-1	0.19	0.29	0.22	<0.10	<0.10	--	<0.10	0.19	<0.50	<0.30	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10		
			AERO-2	<0.10	0.25	15	<0.10	<0.10	--	<0.10	0.19	<0.50	<0.30	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10		
			Average Concentration (mg/L)	0.095	0.27	7.6	ND	ND	--	ND	0.19	ND	ND	ND	ND	ND	ND	ND	ND	ND		
			Standard Deviation (mmoles)	1.8E-04	4.6E-05	2.2E-02	0.0E+00	0.0E+00	--	0.0E+00	2.1E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00		
				Average Total mmoles	0.00013	0.00042	0.016	ND	ND	1.7E-02	ND	0.0088	ND	ND	ND	ND	ND	ND	ND	ND		
20-Nov-14		56	AERO-1	0.17	0.14	0.14	<0.10	<0.10	--	<0.10	0.20	<0.50	<0.30	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10		
			AERO-2	<0.10	<0.10	<0.10	<0.10	<0.10	--	<0.10	0.20	<0.50	<0.30	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10		
			Average Concentration (mg/L)	0.085	0.07	0.072	ND	ND	--	ND	0.20	ND	ND	ND	ND	ND	ND	ND	ND	ND		
			Standard Deviation (mmoles)	1.6E-04	1.6E-04	2.2E-04	0.0E+00	0.0E+00	--	0.0E+00	1.1E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00		
				Average Total mmoles	0.00011	0.00011	0.00015	ND	ND	3.7E-04	ND	0.0093	ND	ND	ND	ND	ND	ND	ND	ND		
26-Nov-14		62	AERO-1	<0.10	<0.10	0.13	<0.10	<0.10	--	<0.10	0.11	<0.50	<0.30	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10		
			AERO-2	<0.10	<0.10	<0.10	<0.10	<0.10	--	<0.10	<0.10	<0.50	<0.30	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10		
			Average Concentration (mg/L)	ND	ND	0.064	ND	ND	--	ND	0.057	ND	ND	ND	ND	ND	ND	ND	ND	ND		
			Standard Deviation (mmoles)	0.0E+00	0.0E+00	1.9E-04	0.0E+00	0.0E+00	--	0.0E+00	3.7E-03	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00		
			Average Total mmoles	ND	ND	0.00014	ND	ND	1.4E-04	ND	0.0026	ND	ND</									

TABLE 2: SUMMARY OF MICROCOSM cVOC, BTEX AND DHG RESULTS
Cranston, Rhode Island

SIREM

Treatment	Date	Day	Replicate	Chlorinated Ethenes and Ethene						Ethane and Methane		Chlorinated Aromatics and BTEX								Comment	
				PCE	TCE	cDCE	VC	Ethene	Total Ethenes	Ethane	Methane	1,2-DCB	1,4-DCB	1,3-DCB	CB	2-CT	Benzene	Toluene	EB		o-Xylene
				mg/L	mg/L	mg/L	mg/L	mg/L	mmol/bottle	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L		mg/L
Second Aerobic ORC [®] -A Amended	07-Oct-14	-1																	Spiked with TCE and cDCE to target concentrations of 0.5 mg/L each.		
																			Spiked with toluene, ethyl benzene, and o-xylene to target concentrations of 20 mg/L, 0.5 mg/L, and 0.4 mg/L, respectively.		
																				Spiked with 1,2-DCB, chlorobenzene, and 2-CT to target concentrations of 30 mg/L, 10 mg/L, and 10 mg/L, respectively.	
	08-Oct-14	0	AERO-2-1	0.82	0.60	0.96	<0.10	<0.10	--	<0.10	0.24	31	0.13	<0.10	14	7.4	0.052	27	0.48	0.42	
			AERO-2-2	0.71	0.50	0.84	<0.10	<0.10	--	<0.10	0.24	27	0.12	<0.10	12	6.1	0.059	24	0.41	0.40	
			Average Concentration (mg/L)	0.77	0.55	0.90	ND	ND	--	ND	0.24	29	0.12	ND	13	6.7	0.055	26	0.45	0.41	
			Standard Deviation (mmoles)	5.6E-02	5.2E-02	5.7E-02	0.0E+00	0.0E+00	--	0.0E+00	1.5E-03	2.1E+00	5.0E-03	0.0E+00	1.0E+00	6.2E-01	3.4E-03	1.7E+00	3.4E-02	9.1E-03	
		Average Total mmoles	0.00098	0.00088	0.0019	ND	ND	3.7E-03	ND	0.011	0.039	0.00017	ND	0.023	0.011	0.00015	0.057	0.00087	0.00079		
	08-Oct-14	0.1																		Amended with 0.01 g ORC [®] -A and began addition of oxygen gas three times a week.	
			AERO-2-1	0.93	0.58	0.96	<0.10	<0.10	--	<0.10	0.22	34	0.11	<0.10	14	7.9	0.06	28	0.52	0.49	
			AERO-2-2	0.72	0.54	0.90	<0.10	<0.10	--	<0.10	0.24	31	0.11	<0.10	13	7.2	0.05	26	0.49	0.44	
			Average Concentration (mg/L)	0.82	0.56	0.93	ND	ND	--	ND	0.23	32	0.11	ND	14	7.6	0.05	27	0.50	0.46	
			Standard Deviation (mmoles)	1.1E-01	1.9E-02	2.9E-02	0.0E+00	0.0E+00	--	0.0E+00	7.2E-03	1.5E+00	1.8E-03	0.0E+00	5.2E-01	3.5E-01	2.3E-03	8.0E-01	1.4E-02	2.4E-02	
			Average Total mmoles	0.0011	0.00089	0.0020	ND	ND	3.9E-03	ND	0.011	0.044	0.00016	ND	0.025	0.012	0.000139	0.060149	0.00098	0.000892	
	17-Oct-14	9	AERO-2-1	0.52	0.37	0.60	<0.10	<0.10	--	<0.10	0.19	23	<0.30	<0.10	0.39	5.8	<0.10	1.0	<0.10	0.39	
			AERO-2-2	0.41	0.52	0.71	<0.10	<0.10	--	<0.10	0.19	27	<0.30	<0.10	1.9	6.6	<0.10	5.9	<0.10	0.45	
			Average Concentration (mg/L)	0.47	0.44	0.65	ND	ND	--	ND	0.19	25	ND	ND	1.1	6.2	ND	3.5	ND	0.42	
			Standard Deviation (mmoles)	5.7E-02	7.5E-02	5.3E-02	0.0E+00	0.0E+00	--	0.0E+00	2.8E-05	2.0E+00	0.0E+00	0.0E+00	7.6E-01	3.7E-01	0.0E+00	2.5E+00	0.0E+00	3.3E-02	
Average Total mmoles			0.00060	0.00070	0.0014	ND	ND	2.7E-03	ND	0.0091	0.035	ND	ND	0.0021	0.010	ND	0.007699	ND	0.000805		
23-Oct-14	15	AERO-2-1	0.30	0.34	0.51	<0.10	<0.10	--	<0.10	0.19	2.5	<0.30	<0.10	<0.10	0.78	<0.10	<0.10	<0.10	0.15		
		AERO-2-2	0.37	0.37	0.40	<0.10	<0.10	--	<0.10	0.19	11	<0.30	<0.10	<0.10	3.8	<0.10	<0.10	<0.10	0.34		
		Average Concentration (mg/L)	0.34	0.35	0.45	ND	ND	--	ND	0.19	6.8	ND	ND	2.3	ND	ND	ND	ND	0.25		
		Standard Deviation (mmoles)	3.1E-02	1.2E-02	5.0E-02	0.0E+00	0.0E+00	--	0.0E+00	5.6E-04	4.3E+00	0.0E+00	0.0E+00	0.0E+00	1.5E+00	0.0E+00	0.0E+00	0.0E+00	9.3E-02		
	Average Total mmoles	0.00043	0.00056	0.00096	ND	ND	2.0E-03	ND	0.0090	0.0093	ND	ND	0.0036	ND	ND	ND	ND	0.000473			
04-Nov-14	27	AERO-2-1	0.17	0.22	0.31	<0.10	<0.10	--	<0.10	0.19	<0.50	<0.30	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10		
		AERO-2-2	0.10	0.19	0.19	<0.10	<0.10	--	<0.10	0.19	0.67	<0.30	<0.10	<0.10	0.12	<0.10	<0.10	<0.10	<0.10		
		Average Concentration (mg/L)	0.13	0.20	0.25	ND	ND	--	ND	0.19	0.40	ND	ND	ND	0.06	ND	ND	ND	ND		
		Standard Deviation (mmoles)	3.4E-02	1.6E-02	5.9E-02	0.0E+00	0.0E+00	--	0.0E+00	1.9E-03	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00		
	Average Total mmoles	0.00017	0.00032	0.00052	ND	ND	1.0E-03	ND	0.0089	0.00054	ND	ND	ND	9.5E-05	ND	ND	ND	ND			
20-Nov-14	43	AERO-2-1	<0.10	0.12	0.18	<0.10	<0.10	--	<0.10	0.20	<0.50	<0.30	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10		
		AERO-2-2	<0.10	0.12	0.12	<0.10	<0.10	--	<0.10	0.21	<0.50	<0.30	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10		
		Average Concentration (mg/L)	ND	0.12	0.15	ND	ND	--	ND	0.21	ND	ND	ND	ND	ND	ND	ND	ND	ND		
		Standard Deviation (mmoles)	0.0E+00	1.8E-03	3.2E-02	0.0E+00	0.0E+00	--	0.0E+00	1.4E-03	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00		
	Average Total mmoles	ND	0.00019	0.00031	ND	ND	5.0E-04	ND	0.0096	ND	ND	ND	ND	ND	ND	ND	ND	ND			

Notes:

- < - compound not detected, the associated value is the detection limit
- µL - microliters
- 1,2-DCB - 1,2-dichlorobenzene
- 1,3-DCB - 1,3-dichlorobenzene
- 1,4-DCB - 1,4-dichlorobenzene
- 2-CT - 2-chlorotoluene
- AERO - aerobic
- ANAC - anaerobic active control
- ANSC - anaerobic sterile control
- CB - chlorobenzene
- cDCE - 1,2-dichloroethene
- EB - ethyl benzene
- g - grams
- LAC/SO4 - lactate and sulfate
- mg/L - milligrams per liter
- mmoles - millimoles
- mmol/bottle - millimole per bottle
- ND - not detected
- o - ortho
- PCE - tetrachloroethene
- TCE - trichloroethene
- VC - vinyl chloride

TABLE 3: SUMMARY OF MICROCOSM ANION RESULTS
Cranston, Rhode Island

Treatment	Date	Day	Treatment Replicate	Total VFAs	Chloride	Nitrite-N	Nitrate-N	Sulfate	Phosphate
				mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Anaerobic Sterile Control	25-Sep-14	0	ANSC-1	9.4	127	<0.09	<0.09	14	<0.07
			ANSC-2	11	114	<0.09	<0.09	15	<0.07
			Average Concentration	10	120	ND	ND	15	ND
	9-Oct-14	14	ANSC-1	11	129	<0.09	0.61	25	0.98
			ANSC-2	6.0	128	<0.09	<0.09	15	0.46
			Average Concentration	8.4	129	ND	0.30	20	0.72
	20-Nov-14	56	ANSC-1	4.9	110	<0.09	<0.09	15	<0.07
			ANSC-2	4.8	105	<0.09	<0.09	13	<0.07
			Average Concentration	4.9	107	ND	ND	14	ND
	25-Feb-15	153	ANSC-1	5.2	199	<0.09	<0.09	13	<0.07
			ANSC-2	6.7	116	<0.09	<0.09	13	<0.07
			Average Concentration	5.9	158	ND	ND	13	ND
	30-Apr-15	217	ANSC-1	11	140	<0.09	<0.09	12	<0.07
			ANSC-2	11	115	<0.09	<0.09	13	<0.07
			Average Concentration	11	128	ND	ND	12	ND
Lactate and Sulfate Amended	25-Sep-14	0	LAC/SO4-1	12	25	<0.09	0.44	297	<0.07
			LAC/SO4-2	11	23	<0.09	0.40	325	<0.07
			Average Concentration	11	24	ND	0.42	311	ND
	9-Oct-14	14	LAC/SO4-1	8.9	27	<0.09	0.38	318	0.28
			LAC/SO4-2	7.2	28	<0.09	0.27	357	0.27
			Average Concentration	8.0	28	ND	0.32	338	0.28
	20-Nov-14	56	LAC/SO4-1	6.2	28	<0.09	<0.09	273	<0.07
			LAC/SO4-2	4.6	20	<0.09	<0.09	256	<0.07
			Average Concentration	5.4	24	ND	ND	264	ND
	31-Dec-14	97	LAC/SO4-1	52	30	<0.09	0.53	250	<0.07
			LAC/SO4-2	54	24	<0.09	<0.09	284	<0.07
			Average Concentration	53	27	ND	0.26	267	ND
	25-Feb-15	153	LAC/SO4-1	8.7	34	<0.09	<0.09	10	<0.07
			LAC/SO4-2	98	32	<0.09	<0.09	244	<0.07
			Average Concentration	53	33	ND	ND	127	ND
	30-Mar-15	186	LAC/SO4-1	74	36	<0.09	<0.09	<0.07	<0.07
			LAC/SO4-2	147	39	<0.09	<0.09	125	<0.07
			Average Concentration	110	38	ND	ND	63	ND
	30-Apr-15	217	LAC/SO4-1	74	35	<0.09	<0.09	<0.07	<0.07
			LAC/SO4-2	95	36	<0.09	<0.09	54	<0.07
			Average Concentration	85	36	ND	ND	27	ND
Nutrisulfate® and Nutrimens® Amended	25-Sep-14	0	NuSO4-1	41	29	<0.09	0.94	529	<0.07
			NuSO4-2	42	28	<0.09	0.72	547	<0.07
			Average Concentration	42	28	ND	0.83	538	ND
	9-Oct-14	14	NuSO4-1	77	28	<0.09	0.26	534	<0.07
			NuSO4-2	54	27	<0.09	0.18	453	<0.07
			Average Concentration	65	27	ND	0.22	493	ND
	20-Nov-14	56	NuSO4-1	77	27	<0.09	0.55	414	<0.07
			NuSO4-2	59	22	<0.09	0.34	364	<0.07
			Average Concentration	68	24	ND	0.44	389	ND
	31-Dec-14	97	NuSO4-1	95	29	<0.09	<0.09	344	<0.07
			NuSO4-2	95	26	<0.09	<0.09	413	<0.07
			Average Concentration	95	28	ND	ND	378	ND
	25-Feb-15	153	NuSO4-1	115	35	<0.09	<0.09	179	<0.07
			NuSO4-2	131	29	<0.09	<0.09	404	<0.07
			Average Concentration	123	32	ND	ND	291	ND
	30-Mar-15	186	NuSO4-1	80	34	<0.09	<0.09	153	<0.07
			NuSO4-2	169	31	<0.09	<0.09	380	<0.07
			Average Concentration	125	32	ND	ND	266	ND
	30-Apr-15	217	NuSO4-1	97	34	<0.09	<0.09	112	3.76
			NuSO4-2	184	31	<0.09	<0.09	371	6.93
			Average Concentration	140	33	ND	ND	242	ND
Original Aerobic ORC® -A Amended	25-Sep-14	0	AERO-1	10	28	<0.09	0.33	18	<0.07
			AERO-2	13	34	<0.09	0.57	30	<0.07
			Average Concentration	12	31	ND	0.45	24	ND
	4-Nov-14	40	AERO-1	6.3	52	<0.09	0.34	75	<0.07
			AERO-2	5.4	43	<0.09	<0.09	62	<0.07
			Average Concentration	5.9	47	ND	0.17	68	ND
	26-Nov-14	62	AERO-1	3.9	49	<0.09	<0.09	96	0.56
			AERO-2	5.1	50	<0.09	<0.09	93	2.0
			Average Concentration	4.5	50	ND	ND	94	1.3

Notes:

< - compound not detected, the associated value is the detection limit

AERO - aerobic

ANSC - anaerobic sterile control

LAC/SO4 - lactate and sulfate

mg/L - milligrams per liter

ND - not detected

NuSO4 - nutrisulfate

VFAs - total volatile fatty acids, calibrated as lactate but may include other VFAs such as formate, acetate, propionate, pyruvate and butyrate

TABLE 4: SUMMARY OF MICROCOSM VFA RESULTS
Cranston, Rhode Island

SIREM

Treatment	Date	Day	Treatment Replicate	Lactate	Acetate	Propionate	Formate	Butyrate	Pyruvate
				mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Lactate and Sulfate Amended	25-Sep-14	0	LAC/SO4-1	<0.39	3.0	<0.31	0.42	<0.41	<0.69
			LAC/SO4-2	<0.39	3.6	<0.31	0.49	<0.41	<0.69
			Average Concentration	ND	3.3	ND	0.46	ND	ND
	31-Dec-14	97	LAC/SO4-1	<0.39	91	<0.31	<0.22	<0.41	<0.69
			LAC/SO4-2	<0.39	105	<0.31	0.25	<0.41	<0.69
			Average Concentration	ND	98	ND	0.13	ND	ND
	25-Feb-15	153	LAC/SO4-1	<0.39	198	1.1	<0.22	<0.41	<0.69
			LAC/SO4-2	<0.39	230	<0.31	<0.22	<0.41	<0.69
			Average Concentration	ND	214	0.56	ND	ND	ND
	30-Mar-15	186	LAC/SO4-1	<0.39	132	<0.31	0.23	<0.41	<0.69
			LAC/SO4-2	<0.39	268	<0.31	<0.22	<0.41	<0.69
			Average Concentration	ND	200	ND	0.12	ND	ND
	30-Apr-15	217	LAC/SO4-1	<0.39	142	0.61	<0.22	<0.41	<0.69
			LAC/SO4-2	<0.39	194	<0.31	0.37	<0.41	<0.69
			Average Concentration	ND	168	0.30	0.18	ND	ND
Nutrisulfate® and Nutrimens® Amended	25-Sep-14	0	NuSO4-1	27	2.8	<0.31	0.75	<0.41	<0.69
			NuSO4-2	26	2.9	<0.31	0.79	<0.41	<0.69
			Average Concentration	26	2.9	ND	0.77	ND	ND
	31-Dec-14	97	NuSO4-1	<0.39	178	<0.31	<0.22	<0.41	<0.69
			NuSO4-2	<0.39	193	<0.31	0.41	<0.41	0.80
			Average Concentration	ND	186	ND	0.21	ND	0.40
	25-Feb-15	153	NuSO4-1	<0.39	137	<0.31	<0.22	<0.41	<0.69
			NuSO4-2	<0.39	262	<0.31	0.54	<0.41	<0.69
			Average Concentration	ND	200	ND	0.27	ND	ND
	30-Mar-15	186	NuSO4-1	<0.39	140	<0.31	<0.22	<0.41	<0.69
			NuSO4-2	<0.39	323	<0.31	0.58	<0.41	<0.69
			Average Concentration	ND	232	ND	0.29	ND	ND
	30-Apr-15	217	NuSO4-1	<0.39	199	<0.31	0.43	<0.41	<0.69
			NuSO4-2	<0.39	384	<0.31	<0.22	<0.41	0.97
			Average Concentration	ND	291	ND	0.21	ND	0.49

Notes:
< - compound not detected, the associated value is the detection limit
LAC/SO4 - lactate and sulfate
mg/L - milligrams per liter
ND - not detected
NuSO4 - nutrisulfate

TABLE 5: SUMMARY OF MICROCOSM pH RESULTS
Cranston, Rhode Island

SiREM

Treatment	Date	Day	Treatment Replicate	pH
Anaerobic Sterile Control	25-Sep-14	0	ANSC-1	5.65
			ANSC-2	5.68
			Average Concentration	5.67
	9-Oct-14	14	ANSC-1	5.71
			ANSC-2	5.61
			Average Concentration	5.66
	23-Oct-14	28	ANSC-1	5.59
			ANSC-2	5.62
			Average Concentration	5.61
	20-Nov-14	56	ANSC-1	5.71
			ANSC-2	5.66
			Average Concentration	5.69
	25-Feb-15	153	ANSC-1	5.90
			ANSC-2	6.01
			Average Concentration	5.96
	30-Apr-15	217	ANSC-1	6.21
			ANSC-2	6.27
			Average Concentration	6.24
Lactate and Sulfate Amended	25-Sep-14	0	LAC/SO4-1	6.42
			LAC/SO4-2	6.53
			Average Concentration	6.48
	9-Oct-14	14	LAC/SO4-1	6.23
			LAC/SO4-2	6.40
			Average Concentration	6.32
	23-Oct-14	28	LAC/SO4-1	6.38
			LAC/SO4-2	6.31
			Average Concentration	6.35
	20-Nov-14	56	LAC/SO4-1	6.50
			LAC/SO4-2	6.44
			Average Concentration	6.47
	31-Dec-14	97	LAC/SO4-1	6.46
			LAC/SO4-2	6.35
			Average Concentration	6.41
	28-Jan-15	125	LAC/SO4-1	6.85
			LAC/SO4-2	6.79
			Average Concentration	6.82
	25-Feb-15	153	LAC/SO4-1	7.06
			LAC/SO4-2	6.70
			Average Concentration	6.88
	30-Mar-15	186	LAC/SO4-1	7.06
			LAC/SO4-2	6.72
			Average Concentration	6.89
	30-Apr-15	217	LAC/SO4-1	7.12
			LAC/SO4-2	6.90
			Average Concentration	7.01
Nutrisulfate® and Nutrimens® Amended	25-Sep-14	0	NuSO4-1	6.41
			NuSO4-2	6.43
			Average Concentration	6.42
	9-Oct-14	14	NuSO4-1	6.26
			NuSO4-2	6.31
			Average Concentration	6.29
	23-Oct-14	28	NuSO4-1	6.22
			NuSO4-2	6.30
			Average Concentration	6.26
	20-Nov-14	56	NuSO4-1	6.33
			NuSO4-2	6.25
			Average Concentration	6.29
	31-Dec-14	97	NuSO4-1	6.32
			NuSO4-2	6.22
			Average Concentration	6.27
	28-Jan-15	125	NuSO4-1	6.72
			NuSO4-2	6.59
			Average Concentration	6.66
	25-Feb-15	153	NuSO4-1	6.75
			NuSO4-2	6.51
			Average Concentration	6.63
	30-Mar-15	186	NuSO4-1	6.83
			NuSO4-2	6.42
			Average Concentration	6.63
	30-Apr-15	217	NuSO4-1	6.74
			NuSO4-2	6.48
			Average Concentration	6.61
First Aerobic ORC®-A Amended	25-Sep-14	0	AERO-1	6.60
			AERO-2	6.90
			Average Concentration	6.75
	17-Oct-14	22	AERO-1	6.36
			AERO-2	6.46
			Average Concentration	6.41
	23-Oct-14	28	AERO-1	6.30
			AERO-2	6.63
			Average Concentration	6.47
	4-Nov-14	40	AERO-1	6.42
			AERO-2	6.72
			Average Concentration	6.57
	20-Nov-14	56	AERO-1	6.31
			AERO-2	6.73
			Average Concentration	6.52
	26-Nov-14	62	AERO-1	6.42
			AERO-2	6.78
			Average Concentration	6.60
Second Aerobic ORC®-A Amended	8-Oct-14	0	AERO-2-1	--
			AERO-2-2	--
			Average Concentration	--
	17-Oct-14	9	AERO-2-1	6.63
			AERO-2-2	6.74
			Average Concentration	6.69
	23-Oct-14	15	AERO-2-1	6.38
			AERO-2-2	6.44
			Average Concentration	6.41
	4-Nov-14	27	AERO-2-1	6.10
			AERO-2-2	6.14
			Average Concentration	6.12
	20-Nov-14	43	AERO-2-1	6.39
			AERO-2-2	6.39
			Average Concentration	6.39

Notes:
-- - not analyzed
AERO - aerobic
ANSC - anaerobic sterile control
LAC/SO4 - lactate and sulfate
NuSO4 - nutrisulfate

TABLE 6: SUMMARY OF MICROCOSM AQUEOUS METALS DATA
Cranston, Rhode Island

Treatment/Control	Date	Time (Days)	Silver (mg/L)	Aluminum (mg/L)	Arsenic (mg/L)	Barium (mg/L)	Beryllium (mg/L)	Boron (mg/L)	Bismuth (mg/L)	Calcium (mg/L)	Cadmium (mg/L)	Cobalt (mg/L)	Chromium (mg/L)	Copper (mg/L)	Iron (mg/L)	Potassium (mg/L)
Anaerobic Sterile Control/Baseline Data	25-Sep-14	0	< 0.000002	< 0.01	0.016	0.097	< 0.000007	0.0887	0.000026	39.2	0.000062	0.00060	0.00239	0.00074	7.39	10.1
			< 0.000002	< 0.01	0.014	0.103	< 0.000007	0.0846	< 0.000007	35.2	0.000010	0.00033	0.00182	0.00023	7.56	9.77
			ND	ND	0.015	0.100	ND	0.0867	0.000013	37.2	0.000036	0.00047	0.00211	0.00049	7.48	9.94
	30-Apr-15	217	0.000013	< 0.1	0.010	0.276	0.000053	0.1040	0.000020	44.1	0.000066	0.00247	0.00082	0.00142	13.7	12.6
			0.0000070	< 0.1	0.0081	0.265	0.000050	0.1040	0.000028	44.3	0.000028	0.00134	0.00052	0.00043	13.4	12.1
			0.000010	ND	0.0091	0.271	0.000052	0.1040	0.000024	44.2	0.000047	0.00191	0.00067	0.00093	13.6	12.4
Lactate and Sulfate Amended	30-Apr-15	217	0.0000060	< 0.1	0.0062	0.088	0.000022	0.098	< 0.000007	44.3	0.000003	0.00049	0.0010	0.00023	0.310	9.32
			0.0000020	< 0.1	0.0042	0.101	0.000023	0.099	0.000011	47.2	0.000005	0.00027	0.0009	0.00014	0.940	10.0
			0.0000040	ND	0.0052	0.095	0.000023	0.099	0.0000055	45.8	0.000004	0.00038	0.0010	0.00019	0.625	9.65
Nutrisulfate® and Nutriments® Amended	30-Apr-15	217	0.000005	< 0.1	0.0095	0.165	0.000027	0.120	0.000020	51.8	0.000005	0.00072	0.0019	0.00043	0.600	23
			< 0.000002	< 0.1	0.0138	0.168	0.000030	0.119	0.000013	53.3	0.000009	0.00076	0.0017	0.00039	0.360	22
			0.0000025	ND	0.0117	0.167	0.000029	0.120	0.000017	52.6	0.000007	0.00074	0.0018	0.00041	0.480	22
Original Aerobic ORC®-A Amended	26-Nov-14	62	< 0.000002	< 0.01	0.0012	0.122	0.000008	0.1000	0.000016	40.8	0.000497	0.00664	0.00032	0.0122	0.082	10.7
			< 0.000002	< 0.01	0.0012	0.140	0.000011	0.0928	0.000012	48.0	0.000578	0.01000	0.00030	0.0145	0.076	10.8
			ND	ND	0.0012	0.131	0.000010	0.0964	0.000014	44.4	0.000538	0.00832	0.00031	0.0134	0.079	10.8

Treatment/Control	Date	Time (Days)	Lithium (mg/L)	Magnesium (mg/L)	Manganese (mg/L)	Molybdenium (mg/L)	Sodium (mg/L)	Nickel (mg/L)	Lead (mg/L)	Antimony (mg/L)	Selenium (mg/L)	Tin (mg/L)	Strontium (mg/L)	Titanium (mg/L)	Thallium (mg/L)	Uranium (mg/L)
Anaerobic Sterile Control/Baseline Data	25-Sep-14	0	0.00535	4.70	0.425	0.0036	22.8	0.0043	0.00013	0.00060	< 0.001	0.00020	0.176	0.00051	0.000069	0.00020
			0.00485	4.67	0.404	0.0029	23.2	0.0042	0.00012	0.00050	< 0.001	0.00016	0.170	0.00071	0.000059	0.000135
			0.00510	4.69	0.415	0.0033	23.0	0.0043	0.00013	0.00055	ND	0.00018	0.173	0.00061	0.000064	0.000168
	30-Apr-15	217	0.00444	7.01	1.84	0.0023	118	0.0077	0.00031	0.00020	< 0.001	0.00007	0.271	0.00037	< 0.000005	0.000023
			0.00470	7.07	1.68	0.0015	119	0.0061	0.00019	0.00020	< 0.001	0.00009	0.281	0.00026	< 0.000005	0.000028
			0.00457	7.04	1.76	0.0019	119	0.0069	0.00025	0.00020	ND	0.00008	0.276	0.00032	ND	0.000026
Lactate and Sulfate Amended	30-Apr-15	217	0.00156	59.2	0.259	0.0001	76.5	0.0033	0.00023	< 0.0002	0.0010	0.0003	0.217	0.00135	< 0.000005	0.000005
			0.00202	60.5	0.358	0.0001	81.0	0.0032	0.00011	< 0.0002	< 0.001	0.0001	0.247	0.00136	< 0.000005	0.000006
			0.00179	59.9	0.309	0.0001	78.8	0.0033	0.00017	0.0000	0.0005	0.0002	0.232	0.00136	ND	0.000006
Nutrisulfate® and Nutriments® Amended	30-Apr-15	217	0.00272	106	0.504	0.0001	28.8	0.0040	0.00029	0.0002	< 0.001	0.0002	0.284	0.00897	< 0.000005	0.000006
			0.00250	102	0.431	0.0001	28.7	0.0044	0.00023	0.0003	0.0010	0.0005	0.281	0.00807	< 0.000005	0.000007
			0.00261	104	0.468	0.0001	28.8	0.0042	0.00026	0.0003	0.0005	0.0003	0.283	0.00852	ND	0.000007
First Aerobic ORC®-A Amended	26-Nov-14	62	0.00213	5.25	0.367	0.0039	26.7	0.0093	0.00030	0.0011	< 0.001	0.00003	0.184	0.00013	0.000053	0.000013
			0.00215	5.43	0.490	0.0032	25.9	0.0097	0.00021	0.0012	< 0.001	0.00002	0.203	0.00008	0.000080	0.000020
			0.00214	5.34	0.429	0.0035	26.3	0.0095	0.00026	0.0012	ND	0.00003	0.194	0.00011	0.000067	0.000017

Treatment/Control	Date	Time (Days)	Vanadium (mg/L)	Tungsten (mg/L)	Yttrium (mg/L)	Zinc (mg/L)
Anaerobic Sterile Control/Baseline Data	25-Sep-14	0	0.00124	0.00021	0.000625	0.015
			0.00096	0.00014	0.000743	0.004
			0.00110	0.00018	0.000684	0.010
	30-Apr-15	217	0.00042	< 0.00002	0.001310	0.040
			0.00034	< 0.00002	0.001320	< 0.02
			0.00038	ND	0.001315	0.020
Lactate and Sulfate Amended	30-Apr-15	217	0.0033	0.0011	0.006050	< 0.02
			0.0019	0.0009	0.003900	< 0.02
			0.0026	0.0010	0.004975	ND
Nutrisulfate® and Nutriments® Amended	30-Apr-15	217	0.0077	0.00032	0.006340	< 0.02
			0.0067	0.00053	0.008440	< 0.02
			0.0072	0.00043	0.007390	ND
First Aerobic ORC®-A Amended	26-Nov-14	62	0.00031	< 0.00002	0.000728	0.028
			0.00034	< 0.00002	0.000398	0.030
			0.00033	ND	0.000563	0.029

Notes:

- < - compound not detected, the associated value is the detection limit
- - not analyzed
- mg/L - milligrams per liter
- ND - not detected

TABLE 7: HALF-LIVES (DAYS) OF cVOCs AND TEX DETECTED IN MICROCOSMS

Cranston, Rhode Island

SiREM

Treatment/Control	PCE			TCE			cDCE			VC		
	Half Life (Days)	t ₁ (Day)	t ₂ (Day)	Half Life (Days)	t ₁ (Day)	t ₂ (Day)	Half Life (Days)	t ₁ (Day)	t ₂ (Day)	Half Life (Days)	t ₁ (Day)	t ₂ (Day)
Anaerobic Sterile Control	110	56	217	NA	NA	NA	772	14	217	NA	NA	NA
Lactate and Sulfate Amended	7.3	0	28	19	14	97	24	56	186	11	153	186
Nutrisulfate [®] and Nutrimens [®] Amended - Replicate 1	3.9	0	14	4.3	0	14	23	28	153	25	97	153
Nutrisulfate [®] and Nutrimens [®] Amended - Replicate 2	3.2	0	14	4.2	0	14	487	28	217	NA	NA	NA
Original Aerobic ORC [®] -A Amended	17	7	62	15*	13	62	14*	13	62	NA	NA	NA
Second Aerobic ORC [®] -A Amended	11	0	43	19	0	43	16	0	43	NA	NA	NA

Treatment/Control	1,2-DCB			CB			2-CT		
	Half Life (Days)	t ₁ (Day)	t ₂ (Day)	Half Life (Days)	t ₁ (Day)	t ₂ (Day)	Half Life (Days)	t ₁ (Day)	t ₂ (Day)
Anaerobic Sterile Control	455	28	217	560	14	217	422	28	217
Lactate and Sulfate Amended	19	28	217	NA	NA	NA	345	28	217
Nutrisulfate [®] and Nutrimens [®] Amended Replicate 1	179	28	217	NA	NA	NA	304	28	217
Nutrisulfate [®] and Nutrimens [®] Amended Replicate 2	373	28	217	502	28	217	399	28	217
Original Aerobic ORC [®] -A Amended	2.0*	13	28	1.4*	13	22	2.7*	13	28
Second Aerobic ORC [®] -A Amended	4.6	0	43	1.9	0	15	5.9	0	43

TABLE 7: HALF-LIVES (DAYS) OF cVOCs AND TEX DETECTED IN MICROCOSMS
Cranston, Rhode Island

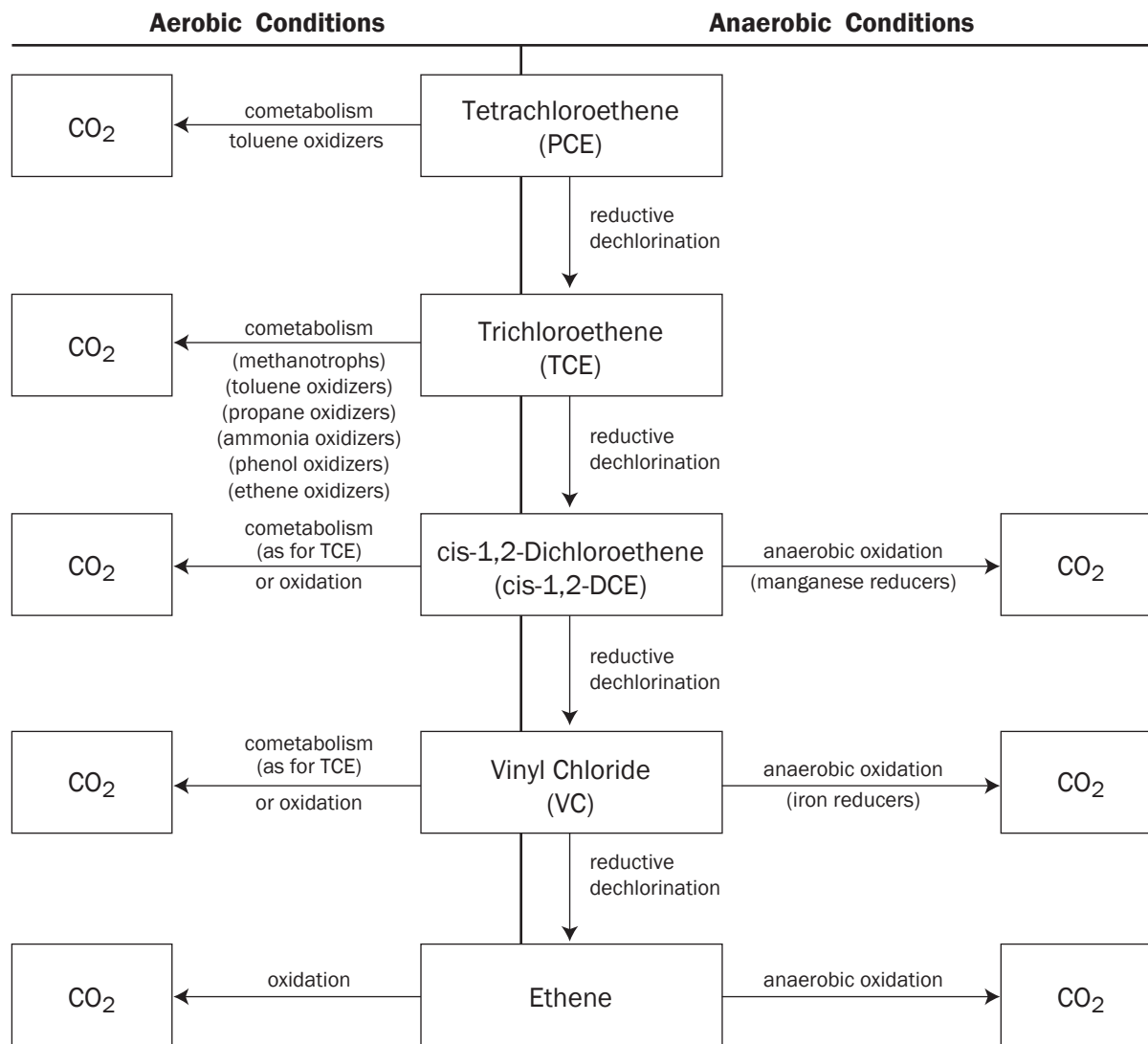
Treatment/Control	Toluene			Ethyl Benzene			o-Xylene		
	Half Life (Days)	t ₁ (Day)	t ₂ (Day)	Half Life (Days)	t ₁ (Day)	t ₂ (Day)	Half Life (Days)	t ₁ (Day)	t ₂ (Day)
Anaerobic Sterile Control	600	14	217	489	14	217	772	14	217
Lactate and Sulfate Amended	30	28	217	536	28	217	587	28	217
Nutrisulfate [®] and Nutrimens [®] Amended Replicate 1	36	28	217	297	28	217	377	28	217
Nutrisulfate [®] and Nutrimens [®] Amended Replicate 2	465	28	217	328	28	217	314	28	217
Original Aerobic ORC [®] -A Amended	1.8*	13	28	4.4*	13	22	7.0*	13	28
Second Aerobic ORC [®] -A Amended	1.7	0	15	2.7	0	9	8.4	0	27

* half life based on the compound concentration after the second spiking event of the aerobic treatment

Notes:

- cDCE - cis-1,2-dichloroethene
- cVOC - chlorinated volatile organic compound
- CB - chlorobenzene
- 2-CT - 2-chlorotoluene
- 1,2-DCB - 1,2-dichlorobenzene
- NA - not applicable
- t₁ - initial time
- t₂ - final time
- PCE - tetrachloroethene
- TCE - trichloroethene
- TEX - toluene, ethyl benzene, and xylenes
- VC - vinyl chloride

FIGURES

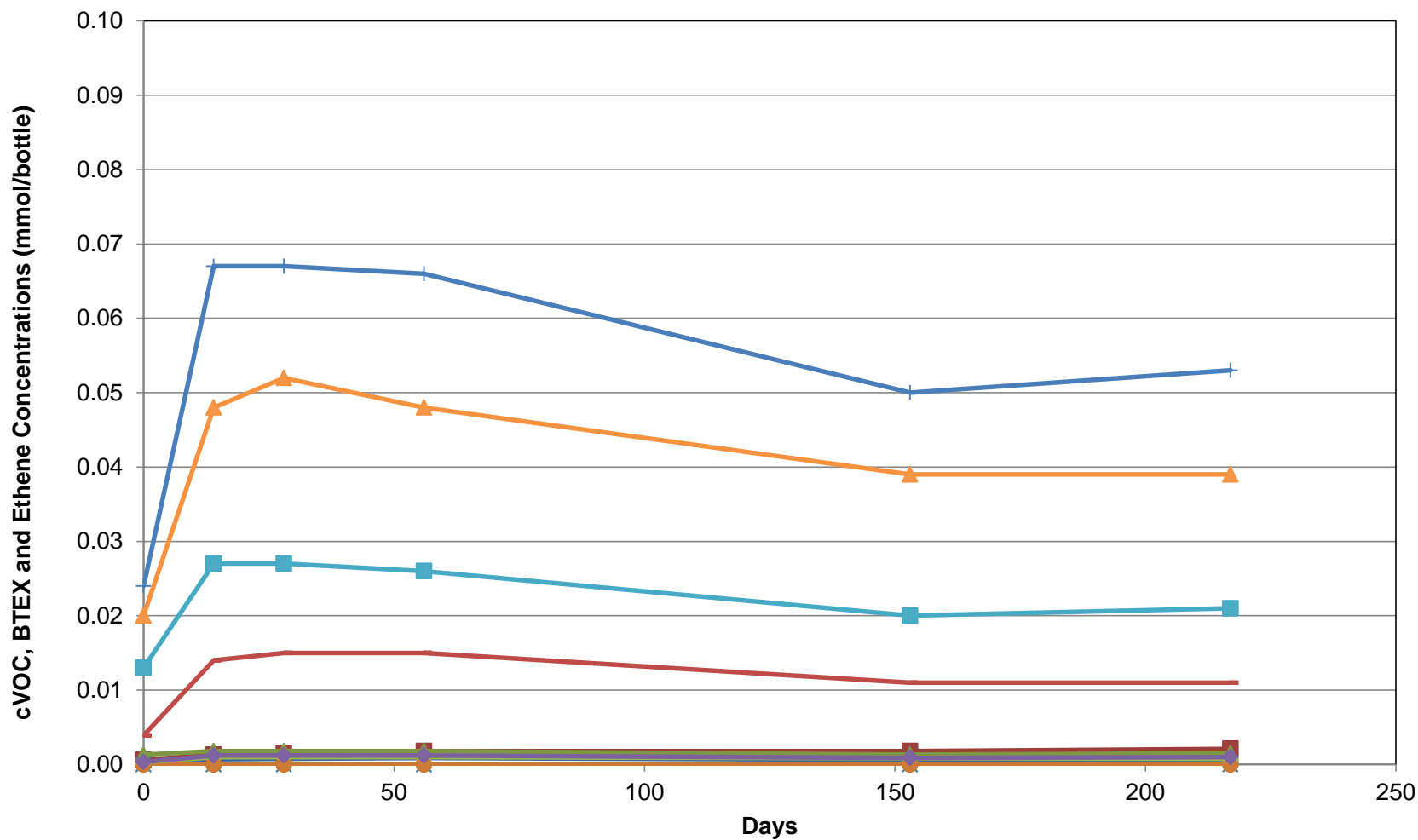


**Pathways for the Degradation
of Chlorinated Ethenes**



June 2014

Figure: **1**

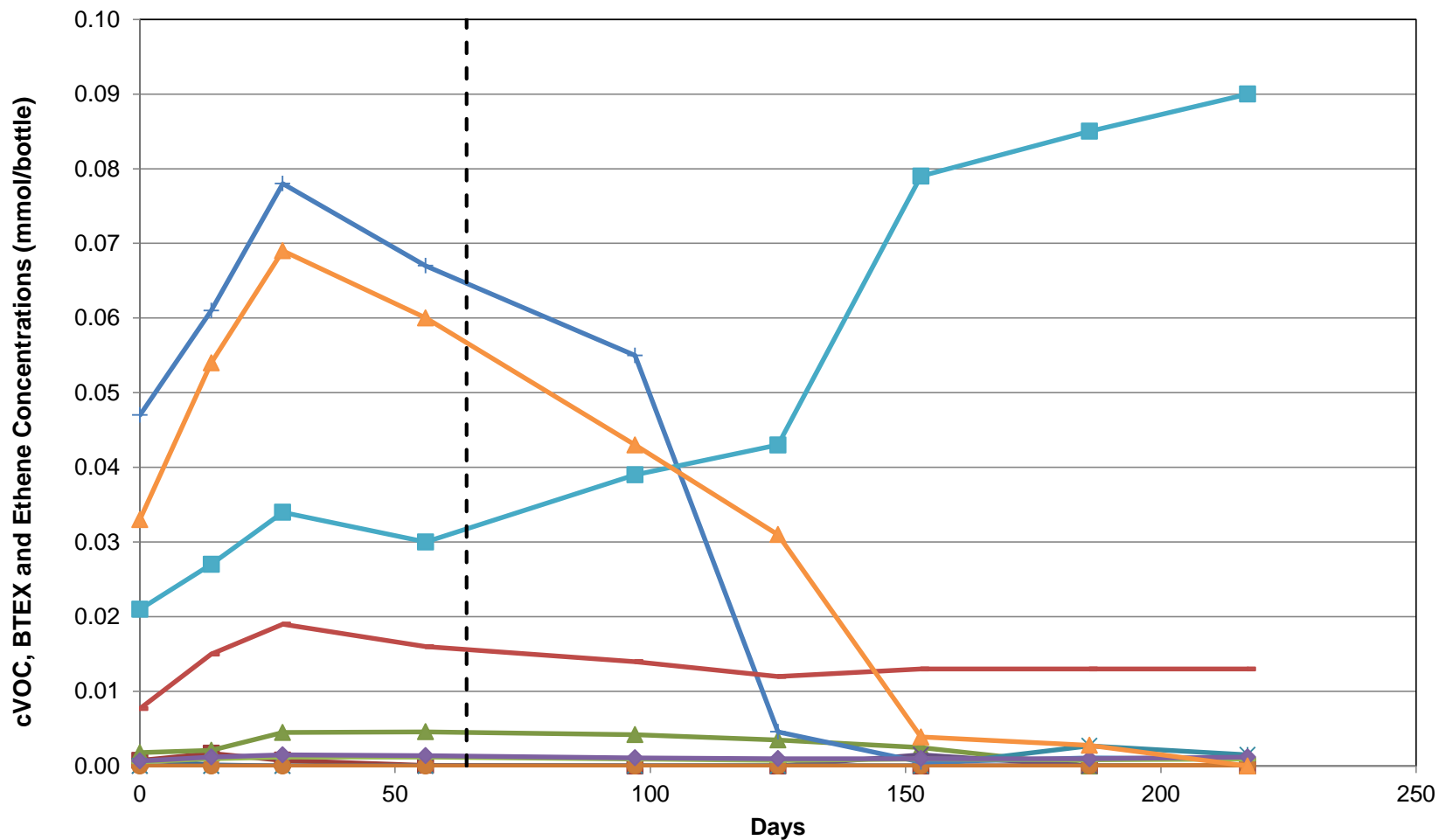


**cVOC, BTEX and Ethene Concentration Trends
in Anaerobic Sterile Control Microcosms**
Cranston, Rhode Island



May 2015

Figure: 2

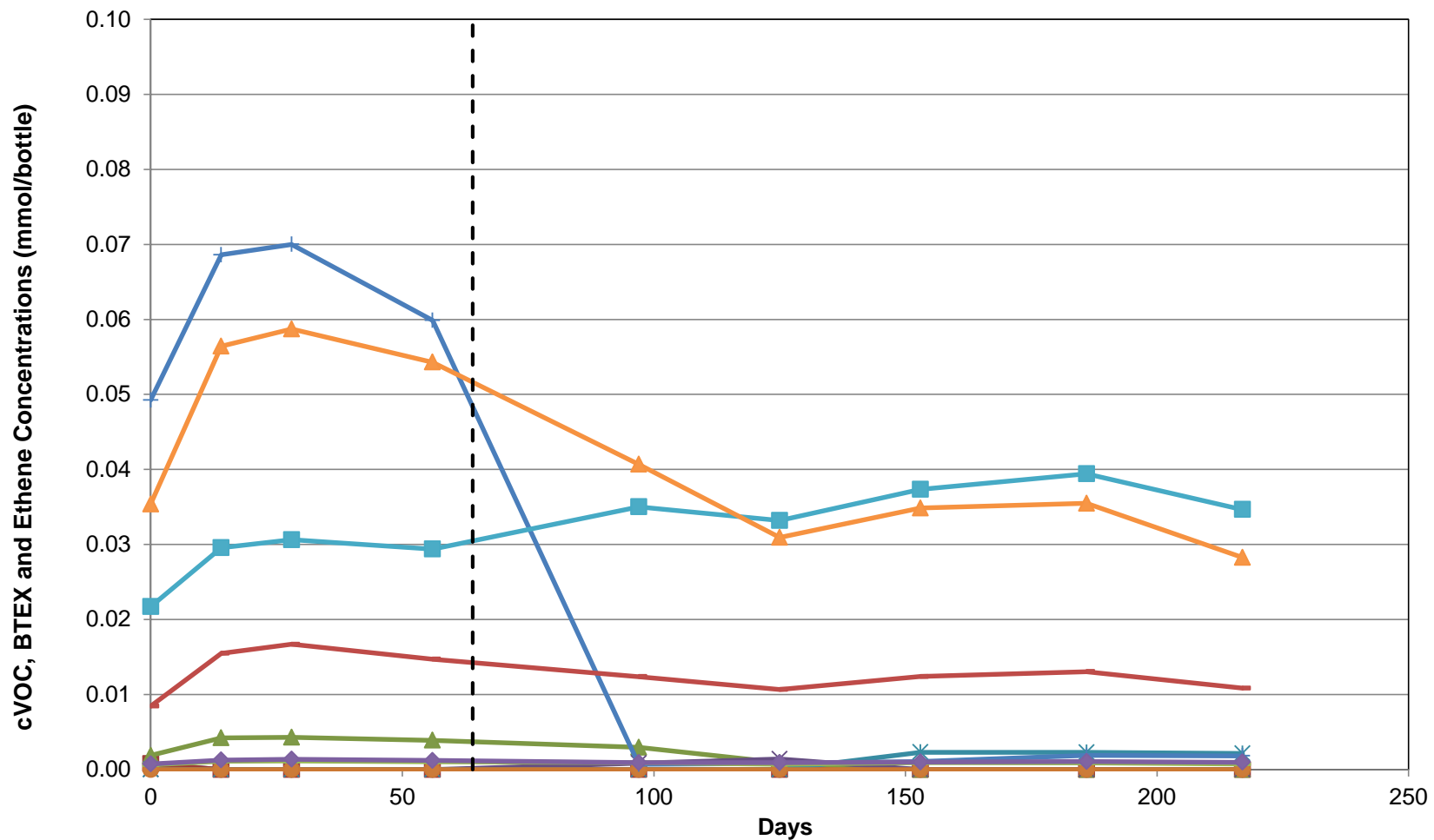


**cVOC, BTEX and Ethene Concentration Trends
in Lactate and Sulfate Amended Microcosms**
Cranston, Rhode Island



May 2015

Figure: 3



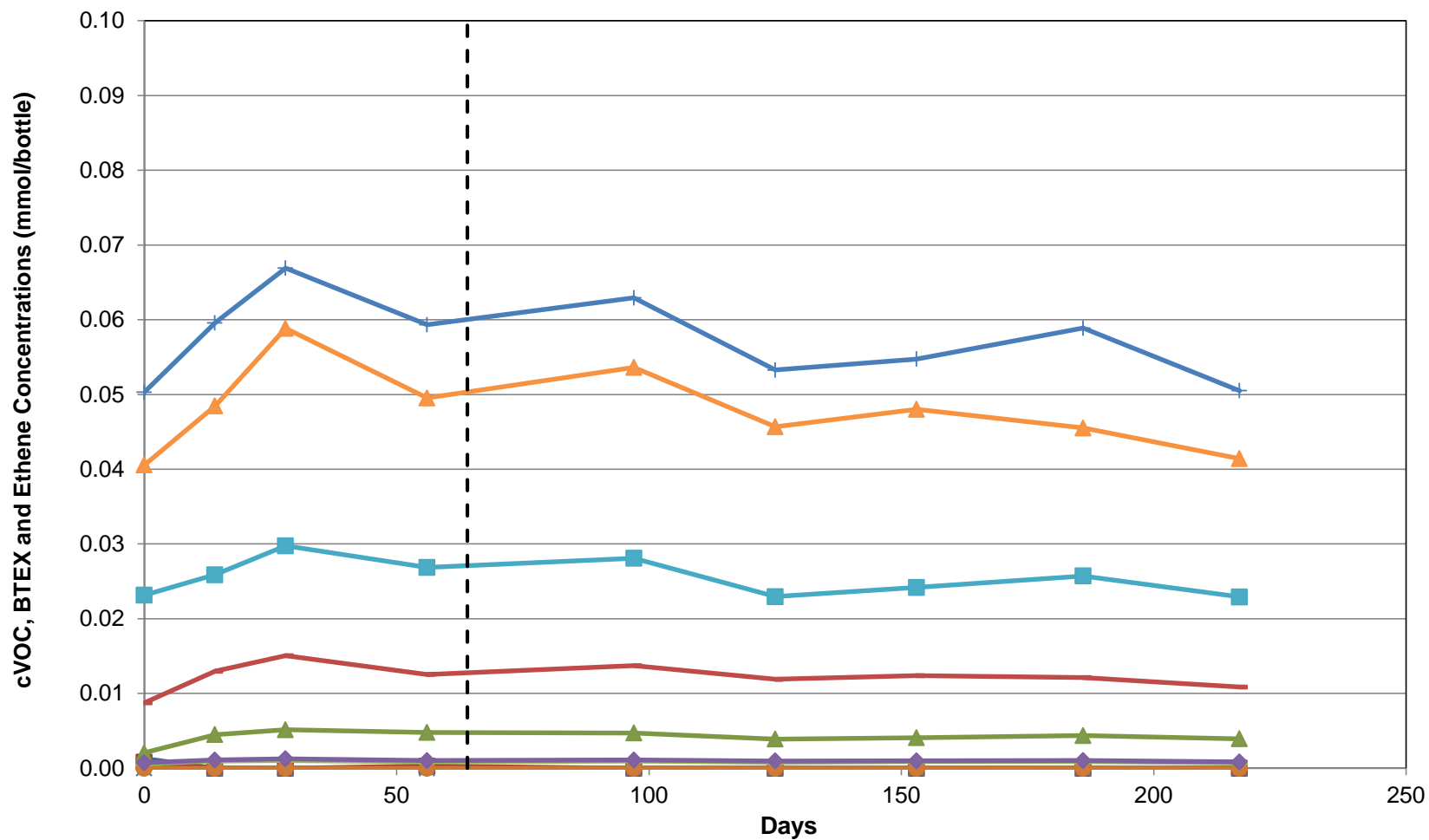
cVOC, BTEX and Ethene Concentration Trends
in Nutrisulfate® and Nutrimens® Amended Microcosm
Replicate 1

Cranston, Rhode Island



May 2015

Figure: 4A

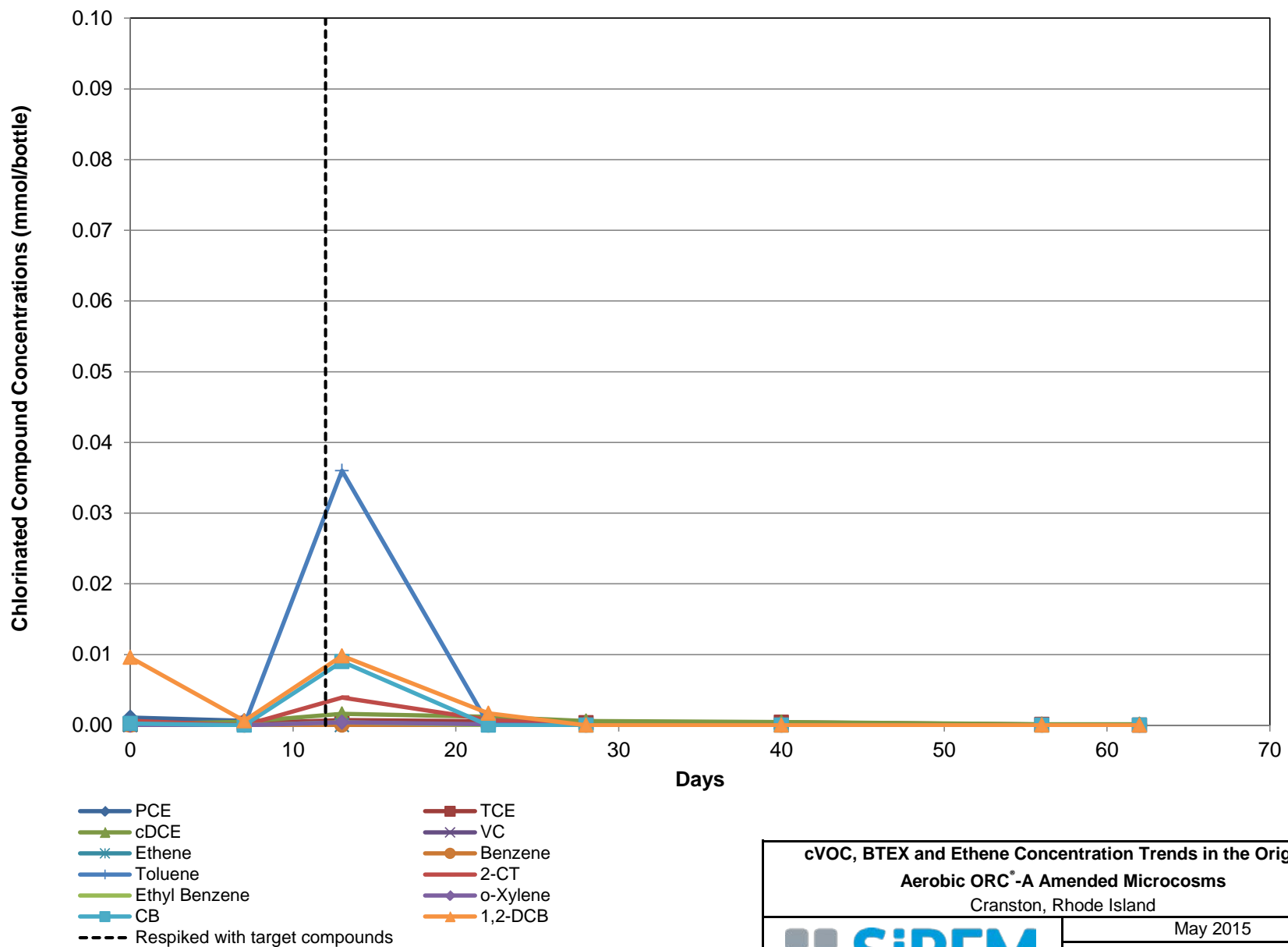


**cVOC, BTEX and Ethene Concentration Trends
in Nutrisulfate® and Nutrimens® Amended Microcosm
Replicate 2
Cranston, Rhode Island**



May 2015

Figure: 4B

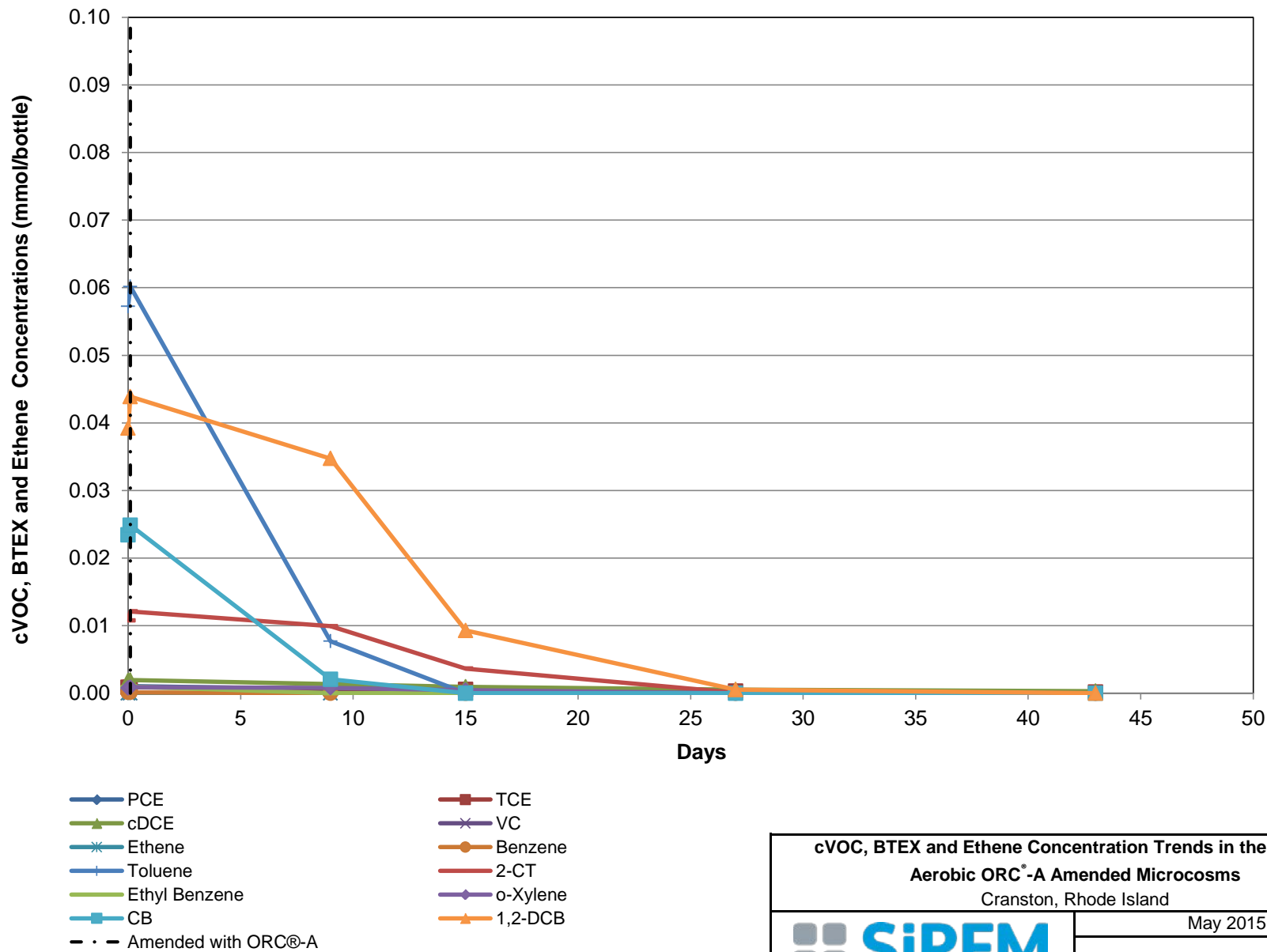


cVOC, BTEX and Ethene Concentration Trends in the Original Aerobic ORC®-A Amended Microcosms
Cranston, Rhode Island



May 2015

Figure: 5



**cVOC, BTEX and Ethene Concentration Trends in the Second
Aerobic ORC®-A Amended Microcosms**
Cranston, Rhode Island



May 2015

Figure: 6

APPENDIX A: Chain of Custody Documentation

[illegible]

Distribution: White - return to Originator: Yellow - Lab Copy: Pink - Retained by Client

* *Mandatory Fields*



Chain-of-Custody Form

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Page 1 of 1

Lab # S-3343

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APPENDIX B: ALS Environmental Laboratory Report



SIREM
ATTN: Jeff Roberts
130 Research Lane
Suite 2
Guelph ON N1G 5G3

Date Received: 26-SEP-14
Report Date: 06-OCT-14 11:42 (MT)
Version: FINAL

Client Phone: 519-515-0840

Certificate of Analysis

Lab Work Order #: L1524406
Project P.O. #: NOT SUBMITTED
Job Reference:
C of C Numbers:
Legal Site Desc:

Mathumai Ganeshkumar
Account Manager

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ADDRESS: 60 Northland Road, Unit 1, Waterloo, ON N2V 2B8 Canada | Phone: +1 519 886 6910 | Fax: +1 519 886 9047
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ALS ENVIRONMENTAL ANALYTICAL REPORT

Sample Details/Parameters		Result	Qualifier*	D.L.	Units	Extracted	Analyzed	Batch
L1524406-1 RI-250914-2-CT-1								
Sampled By: MICHAEL HEALEY on 25-SEP-14 @ 14:30								
Matrix: WATER								
Volatile Organic Compounds								
Acetone		<2000	DLA	2000	ug/L		06-OCT-14	R2971010
Benzene		<50	DLA	50	ug/L		06-OCT-14	R2971010
Bromobenzene		<50	DLA	50	ug/L		06-OCT-14	R2971010
Bromochloromethane		<50	DLA	50	ug/L		06-OCT-14	R2971010
Bromodichloromethane		<200	DLA	200	ug/L		06-OCT-14	R2971010
Bromoform		<100	DLA	100	ug/L		06-OCT-14	R2971010
Bromomethane		<100	DLA	100	ug/L		06-OCT-14	R2971010
n-Butylbenzene		<500	DLA	500	ug/L		06-OCT-14	R2971010
sec-Butylbenzene		<500	DLA	500	ug/L		06-OCT-14	R2971010
tert-Butylbenzene		<500	DLA	500	ug/L		06-OCT-14	R2971010
Carbon Disulfide		<200	DLA	200	ug/L		06-OCT-14	R2971010
Carbon tetrachloride		<50	DLA	50	ug/L		06-OCT-14	R2971010
Chlorobenzene		9230	DLA	50	ug/L		06-OCT-14	R2971010
Dibromochloromethane		<100	DLA	100	ug/L		06-OCT-14	R2971010
Chloroethane		<100	DLA	100	ug/L		06-OCT-14	R2971010
Chloroform		<100	DLA	100	ug/L		06-OCT-14	R2971010
Chloromethane		<100	DLA	100	ug/L		06-OCT-14	R2971010
2-Chlorotoluene		3300	DLA	2000	ug/L		06-OCT-14	R2971010
4-Chlorotoluene		<2000	DLA	2000	ug/L		06-OCT-14	R2971010
1,2-Dibromo-3-chloropropane		<2000	DLA	2000	ug/L		06-OCT-14	R2971010
1,2-Dibromoethane		<50	DLA	50	ug/L		06-OCT-14	R2971010
Dibromomethane		<50	DLA	50	ug/L		06-OCT-14	R2971010
1,2-Dichlorobenzene		21600	DLA	50	ug/L		06-OCT-14	R2971010
1,3-Dichlorobenzene		<50	DLA	50	ug/L		06-OCT-14	R2971010
1,4-Dichlorobenzene		<50	DLA	50	ug/L		06-OCT-14	R2971010
Dichlorodifluoromethane		<100	DLA	100	ug/L		06-OCT-14	R2971010
1,1-Dichloroethane		<50	DLA	50	ug/L		06-OCT-14	R2971010
1,2-Dichloroethane		<50	DLA	50	ug/L		06-OCT-14	R2971010
1,1-Dichloroethylene		<50	DLA	50	ug/L		06-OCT-14	R2971010
cis-1,2-Dichloroethylene		574	DLA	50	ug/L		06-OCT-14	R2971010
trans-1,2-Dichloroethylene		<50	DLA	50	ug/L		06-OCT-14	R2971010
Dichloromethane		<500	DLA	500	ug/L		06-OCT-14	R2971010
1,2-Dichloropropane		<50	DLA	50	ug/L		06-OCT-14	R2971010
1,3-Dichloropropane		<50	DLA	50	ug/L		06-OCT-14	R2971010
2,2-Dichloropropane		<50	DLA	50	ug/L		06-OCT-14	R2971010
1,1-Dichloropropene		<50	DLA	50	ug/L		06-OCT-14	R2971010
cis-1,3-Dichloropropene		<50	DLA	50	ug/L		06-OCT-14	R2971010
trans-1,3-Dichloropropene		<50	DLA	50	ug/L		06-OCT-14	R2971010
Ethyl Benzene		197	DLA	50	ug/L		06-OCT-14	R2971010
Hexachlorobutadiene		<500	DLA	500	ug/L		06-OCT-14	R2971010
n-Hexane		<50	DLA	50	ug/L		06-OCT-14	R2971010

* Refer to Referenced Information for Qualifiers (if any) and Methodology.

ALS ENVIRONMENTAL ANALYTICAL REPORT

Sample Details/Parameters		Result	Qualifier*	D.L.	Units	Extracted	Analyzed	Batch
L1524406-1 RI-250914-2-CT-1 Sampled By: MICHAEL HEALEY on 25-SEP-14 @ 14:30 Matrix: WATER								
Volatile Organic Compounds								
2-Hexanone		<2000	DLA	2000	ug/L		06-OCT-14	R2971010
Isopropylbenzene		<500	DLA	500	ug/L		06-OCT-14	R2971010
Isopropyltoluene		<500	DLA	500	ug/L		06-OCT-14	R2971010
Methyl Ethyl Ketone		<2000	DLA	2000	ug/L		06-OCT-14	R2971010
Methyl Isobutyl Ketone		<2000	DLA	2000	ug/L		06-OCT-14	R2971010
MTBE		<200	DLA	200	ug/L		06-OCT-14	R2971010
Naphthalene		<1000	DLA	1000	ug/L		06-OCT-14	R2971010
n-Propylbenzene		<500	DLA	500	ug/L		06-OCT-14	R2971010
Styrene		<50	DLA	50	ug/L		06-OCT-14	R2971010
1,1,1,2-Tetrachloroethane		<50	DLA	50	ug/L		06-OCT-14	R2971010
1,1,2,2-Tetrachloroethane		<50	DLA	50	ug/L		06-OCT-14	R2971010
Tetrachloroethylene		555	DLA	50	ug/L		06-OCT-14	R2971010
Toluene		14800	DLA	50	ug/L		06-OCT-14	R2971010
1,2,3-Trichlorobenzene		<1000	DLA	1000	ug/L		06-OCT-14	R2971010
1,2,4-Trichlorobenzene		<1000	DLA	1000	ug/L		06-OCT-14	R2971010
1,1,1-Trichloroethane		<50	DLA	50	ug/L		06-OCT-14	R2971010
1,1,2-Trichloroethane		<50	DLA	50	ug/L		06-OCT-14	R2971010
Trichloroethylene		550	DLA	50	ug/L		06-OCT-14	R2971010
Trichlorofluoromethane		<100	DLA	100	ug/L		06-OCT-14	R2971010
1,2,3-Trichloropropane		<50	DLA	50	ug/L		06-OCT-14	R2971010
1,2,4-Trimethylbenzene		<50	DLA	50	ug/L		06-OCT-14	R2971010
1,3,5-Trimethylbenzene		<50	DLA	50	ug/L		06-OCT-14	R2971010
Vinyl chloride		<50	DLA	50	ug/L		06-OCT-14	R2971010
o-Xylene		229	DLA	50	ug/L		06-OCT-14	R2971010
m+p-Xylenes		<100	DLA	100	ug/L		06-OCT-14	R2971010
Surrogate: 4-Bromofluorobenzene		90.4		70-130	%		06-OCT-14	R2971010
Surrogate: 1,4-Difluorobenzene		98.8		70-130	%		06-OCT-14	R2971010
L1524406-2 RI-250914-2-CT-2 Sampled By: MICHAEL HEALEY on 25-SEP-14 @ 14:30 Matrix: WATER								
Volatile Organic Compounds								
Acetone		<2000	DLA	2000	ug/L		06-OCT-14	R2971010
Benzene		<50	DLA	50	ug/L		06-OCT-14	R2971010
Bromobenzene		<50	DLA	50	ug/L		06-OCT-14	R2971010
Bromochloromethane		<50	DLA	50	ug/L		06-OCT-14	R2971010
Bromodichloromethane		<200	DLA	200	ug/L		06-OCT-14	R2971010
Bromoform		<100	DLA	100	ug/L		06-OCT-14	R2971010
Bromomethane		<100	DLA	100	ug/L		06-OCT-14	R2971010
n-Butylbenzene		<500	DLA	500	ug/L		06-OCT-14	R2971010
sec-Butylbenzene		<500	DLA	500	ug/L		06-OCT-14	R2971010
tert-Butylbenzene		<500	DLA	500	ug/L		06-OCT-14	R2971010
Carbon Disulfide		<200	DLA	200	ug/L		06-OCT-14	R2971010

* Refer to Referenced Information for Qualifiers (if any) and Methodology.

ALS ENVIRONMENTAL ANALYTICAL REPORT

Sample Details/Parameters		Result	Qualifier*	D.L.	Units	Extracted	Analyzed	Batch
L1524406-2 RI-250914-2-CT-2								
Sampled By: MICHAEL HEALEY on 25-SEP-14 @ 14:30								
Matrix: WATER								
Volatile Organic Compounds								
Carbon tetrachloride		<50	DLA	50	ug/L		06-OCT-14	R2971010
Chlorobenzene		11600	DLA	50	ug/L		06-OCT-14	R2971010
Dibromochloromethane		<100	DLA	100	ug/L		06-OCT-14	R2971010
Chloroethane		<100	DLA	100	ug/L		06-OCT-14	R2971010
Chloroform		<100	DLA	100	ug/L		06-OCT-14	R2971010
Chloromethane		<100	DLA	100	ug/L		06-OCT-14	R2971010
2-Chlorotoluene		4100	DLA	2000	ug/L		06-OCT-14	R2971010
4-Chlorotoluene		<2000	DLA	2000	ug/L		06-OCT-14	R2971010
1,2-Dibromo-3-chloropropane		<2000	DLA	2000	ug/L		06-OCT-14	R2971010
1,2-Dibromoethane		<50	DLA	50	ug/L		06-OCT-14	R2971010
Dibromomethane		<50	DLA	50	ug/L		06-OCT-14	R2971010
1,2-Dichlorobenzene		25900	DLA	50	ug/L		06-OCT-14	R2971010
1,3-Dichlorobenzene		<50	DLA	50	ug/L		06-OCT-14	R2971010
1,4-Dichlorobenzene		<50	DLA	50	ug/L		06-OCT-14	R2971010
Dichlorodifluoromethane		<100	DLA	100	ug/L		06-OCT-14	R2971010
1,1-Dichloroethane		<50	DLA	50	ug/L		06-OCT-14	R2971010
1,2-Dichloroethane		<50	DLA	50	ug/L		06-OCT-14	R2971010
1,1-Dichloroethylene		<50	DLA	50	ug/L		06-OCT-14	R2971010
cis-1,2-Dichloroethylene		564	DLA	50	ug/L		06-OCT-14	R2971010
trans-1,2-Dichloroethylene		<50	DLA	50	ug/L		06-OCT-14	R2971010
Dichloromethane		<500	DLA	500	ug/L		06-OCT-14	R2971010
1,2-Dichloropropane		<50	DLA	50	ug/L		06-OCT-14	R2971010
1,3-Dichloropropane		<50	DLA	50	ug/L		06-OCT-14	R2971010
2,2-Dichloropropane		<50	DLA	50	ug/L		06-OCT-14	R2971010
1,1-Dichloropropene		<50	DLA	50	ug/L		06-OCT-14	R2971010
cis-1,3-Dichloropropene		596	DLA	50	ug/L		06-OCT-14	R2971010
trans-1,3-Dichloropropene		<50	DLA	50	ug/L		06-OCT-14	R2971010
Ethyl Benzene		263	DLA	50	ug/L		06-OCT-14	R2971010
Hexachlorobutadiene		<500	DLA	500	ug/L		06-OCT-14	R2971010
n-Hexane		<50	DLA	50	ug/L		06-OCT-14	R2971010
2-Hexanone		<2000	DLA	2000	ug/L		06-OCT-14	R2971010
Isopropylbenzene		<500	DLA	500	ug/L		06-OCT-14	R2971010
Isopropyltoluene		<500	DLA	500	ug/L		06-OCT-14	R2971010
Methyl Ethyl Ketone		<2000	DLA	2000	ug/L		06-OCT-14	R2971010
Methyl Isobutyl Ketone		<2000	DLA	2000	ug/L		06-OCT-14	R2971010
MTBE		<200	DLA	200	ug/L		06-OCT-14	R2971010
Naphthalene		<1000	DLA	1000	ug/L		06-OCT-14	R2971010
n-Propylbenzene		<500	DLA	500	ug/L		06-OCT-14	R2971010
Styrene		<50	DLA	50	ug/L		06-OCT-14	R2971010
1,1,1,2-Tetrachloroethane		<50	DLA	50	ug/L		06-OCT-14	R2971010
1,1,2,2-Tetrachloroethane		<50	DLA	50	ug/L		06-OCT-14	R2971010

* Refer to Referenced Information for Qualifiers (if any) and Methodology.

Sample Details/Parameters		Result	Qualifier*	D.L.	Units	Extracted	Analyzed	Batch
L1524406-2	RI-250914-2-CT-2							
Sampled By:	MICHAEL HEALEY on 25-SEP-14 @ 14:30							
Matrix:	WATER							
Volatile Organic Compounds								
Tetrachloroethylene		175	DLA	50	ug/L		06-OCT-14	R2971010
Toluene		18000	DLA	50	ug/L		06-OCT-14	R2971010
1,2,3-Trichlorobenzene		<1000	DLA	1000	ug/L		06-OCT-14	R2971010
1,2,4-Trichlorobenzene		<1000	DLA	1000	ug/L		06-OCT-14	R2971010
1,1,1-Trichloroethane		<50	DLA	50	ug/L		06-OCT-14	R2971010
1,1,2-Trichloroethane		<50	DLA	50	ug/L		06-OCT-14	R2971010
Trichloroethylene		1150	DLA	50	ug/L		06-OCT-14	R2971010
Trichlorofluoromethane		<100	DLA	100	ug/L		06-OCT-14	R2971010
1,2,3-Trichloropropane		<50	DLA	50	ug/L		06-OCT-14	R2971010
1,2,4-Trimethylbenzene		<50	DLA	50	ug/L		06-OCT-14	R2971010
1,3,5-Trimethylbenzene		<50	DLA	50	ug/L		06-OCT-14	R2971010
Vinyl chloride		<50	DLA	50	ug/L		06-OCT-14	R2971010
o-Xylene		289	DLA	50	ug/L		06-OCT-14	R2971010
m+p-Xylenes		<100	DLA	100	ug/L		06-OCT-14	R2971010
Surrogate: 4-Bromofluorobenzene		89.1		70-130	%		06-OCT-14	R2971010
Surrogate: 1,4-Difluorobenzene		98.4		70-130	%		06-OCT-14	R2971010

* Refer to Referenced Information for Qualifiers (if any) and Methodology.

Reference Information

Sample Parameter Qualifier key listed:

Qualifier	Description
DLA	Detection Limit adjusted for required dilution

Test Method References:

ALS Test Code	Matrix	Test Description	Method Reference**
VOC-ROU1-HS-WT	Water	Volatile Organic Compounds	SW846 8260
Aqueous samples are analyzed by headspace-GC/MS.			

** ALS test methods may incorporate modifications from specified reference methods to improve performance.

The last two letters of the above test code(s) indicate the laboratory that performed analytical analysis for that test. Refer to the list below:

Laboratory Definition Code	Laboratory Location
WT	ALS ENVIRONMENTAL - WATERLOO, ONTARIO, CANADA

Chain of Custody Numbers:**GLOSSARY OF REPORT TERMS**

Surrogates are compounds that are similar in behaviour to target analyte(s), but that do not normally occur in environmental samples. For applicable tests, surrogates are added to samples prior to analysis as a check on recovery. In reports that display the D.L. column, laboratory objectives for surrogates are listed there.

mg/kg - milligrams per kilogram based on dry weight of sample

mg/kg wwt - milligrams per kilogram based on wet weight of sample

mg/kg lwt - milligrams per kilogram based on lipid weight of sample

mg/L - unit of concentration based on volume, parts per million.

< - Less than.

D.L. - The reporting limit.

N/A - Result not available. Refer to qualifier code and definition for explanation.

Test results reported relate only to the samples as received by the laboratory.

UNLESS OTHERWISE STATED, ALL SAMPLES WERE RECEIVED IN ACCEPTABLE CONDITION.

Analytical results in unsigned test reports with the DRAFT watermark are subject to change, pending final QC review.



Quality Control Report

Workorder: L1524406

Report Date: 06-OCT-14

Page 1 of 8

Client: SIREM
130 Research Lane Suite 2
Guelph ON N1G 5G3

Contact: Jeff Roberts

Test	Matrix	Reference	Result	Qualifier	Units	RPD	Limit	Analyzed
VOC-ROU1-HS-WT		Water						
Batch	R2971010							
WG1963525-1	CVS							
1,1,1,2-Tetrachloroethane			99.7		%		70-130	03-OCT-14
1,1,2,2-Tetrachloroethane			91.4		%		70-130	03-OCT-14
1,1,1-Trichloroethane			104.3		%		70-130	03-OCT-14
1,1,2-Trichloroethane			91.7		%		70-130	03-OCT-14
1,1-Dichloroethane			100.9		%		70-130	03-OCT-14
1,1-Dichloroethylene			95.2		%		70-130	03-OCT-14
1,1-Dichloropropene			95.5		%		70-130	03-OCT-14
1,2,3-Trichloropropane			81.0		%		70-130	03-OCT-14
1,2,3-Trichlorobenzene			107.2		%		70-130	03-OCT-14
1,2,4-Trichlorobenzene			111.1		%		70-130	03-OCT-14
1,2,4-Trimethylbenzene			105.8		%		70-130	03-OCT-14
1,2-Dibromo-3-chloropropane			86.0		%		70-130	03-OCT-14
1,2-Dibromoethane			90.4		%		70-130	03-OCT-14
1,2-Dichlorobenzene			101.8		%		70-130	03-OCT-14
1,2-Dichloroethane			92.5		%		70-130	03-OCT-14
1,2-Dichloropropane			90.7		%		70-130	03-OCT-14
1,3,5-Trimethylbenzene			107.7		%		70-130	03-OCT-14
1,3-Dichlorobenzene			104.9		%		70-130	03-OCT-14
1,3-Dichloropropane			89.0		%		70-130	03-OCT-14
1,4-Dichlorobenzene			101.5		%		70-130	03-OCT-14
2,2-Dichloropropane			88.3		%		70-130	03-OCT-14
2-Chlorotoluene			101.1		%		70-130	03-OCT-14
2-Hexanone			73.2		%		70-130	03-OCT-14
4-Chlorotoluene			104.4		%		70-130	03-OCT-14
Acetone			91.9		%		70-130	03-OCT-14
Benzene			95.6		%		70-130	03-OCT-14
Bromobenzene			96.0		%		70-130	03-OCT-14
Bromochloromethane			91.3		%		70-130	03-OCT-14
Bromodichloromethane			90.4		%		70-130	03-OCT-14
Bromoform			91.2		%		70-130	03-OCT-14
Bromomethane			96.2		%		70-130	03-OCT-14
Carbon Disulfide			105.7		%		70-130	03-OCT-14
Carbon tetrachloride			106.2		%		70-130	03-OCT-14



Quality Control Report

Workorder: L1524406

Report Date: 06-OCT-14

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Client: SIREM
130 Research Lane Suite 2
Guelph ON N1G 5G3

Contact: Jeff Roberts

Test	Matrix	Reference	Result	Qualifier	Units	RPD	Limit	Analyzed
VOC-ROU1-HS-WT		Water						
Batch	R2971010							
WG1963525-1	CVS							
Chlorobenzene			99.9		%		70-130	03-OCT-14
Chloroethane			98.9		%		70-130	03-OCT-14
Chloroform			98.1		%		70-130	03-OCT-14
Chloromethane			95.1		%		70-130	03-OCT-14
cis-1,2-Dichloroethylene			94.5		%		70-130	03-OCT-14
cis-1,3-Dichloropropene			94.1		%		70-130	03-OCT-14
Dibromochloromethane			94.4		%		70-130	03-OCT-14
Dibromomethane			88.1		%		70-130	03-OCT-14
Dichlorodifluoromethane			90.3		%		70-130	03-OCT-14
Dichloromethane			94.8		%		70-130	03-OCT-14
Ethyl Benzene			103.7		%		70-130	03-OCT-14
Hexachlorobutadiene			127.9		%		70-130	03-OCT-14
n-Hexane			107.9		%		70-130	03-OCT-14
Isopropylbenzene			108.8		%		70-130	03-OCT-14
Isopropyltoluene			108.8		%		70-130	03-OCT-14
m+p-Xylenes			107.9		%		70-130	03-OCT-14
Methyl Ethyl Ketone			81.1		%		70-130	03-OCT-14
Methyl Isobutyl Ketone			70.3		%		70-130	03-OCT-14
MTBE			92.9		%		70-130	03-OCT-14
Naphthalene			90.4		%		70-130	03-OCT-14
n-Butylbenzene			120.4		%		70-130	03-OCT-14
n-Propylbenzene			111.0		%		70-130	03-OCT-14
o-Xylene			102.1		%		70-130	03-OCT-14
sec-Butylbenzene			111.5		%		70-130	03-OCT-14
Styrene			97.2		%		70-130	03-OCT-14
tert-Butylbenzene			108.8		%		70-130	03-OCT-14
Tetrachloroethylene			110.3		%		70-130	03-OCT-14
Toluene			96.2		%		70-130	03-OCT-14
trans-1,2-Dichloroethylene			95.8		%		70-130	03-OCT-14
trans-1,3-Dichloropropene			89.9		%		70-130	03-OCT-14
Trichloroethylene			101.5		%		70-130	03-OCT-14
Trichlorofluoromethane			110.2		%		70-130	03-OCT-14
Vinyl chloride			102.1		%		70-130	03-OCT-14
WG1963525-4	DUP	WG1963525-3						

Quality Control Report

Workorder: L1524406

Report Date: 06-OCT-14

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Client: SIREM
130 Research Lane Suite 2
Guelph ON N1G 5G3

Contact: Jeff Roberts

Test	Matrix	Reference	Result	Qualifier	Units	RPD	Limit	Analyzed
VOC-ROU1-HS-WT		Water						
Batch	R2971010							
WG1963525-4	DUP	WG1963525-3						
1,1,1,2-Tetrachloroethane		<0.50	<0.50	RPD-NA	ug/L	N/A	30	03-OCT-14
1,1,2,2-Tetrachloroethane		<0.50	<0.50	RPD-NA	ug/L	N/A	30	03-OCT-14
1,1,1-Trichloroethane		<0.50	<0.50	RPD-NA	ug/L	N/A	30	03-OCT-14
1,1,2-Trichloroethane		<0.50	<0.50	RPD-NA	ug/L	N/A	30	03-OCT-14
1,1-Dichloroethane		<0.50	<0.50	RPD-NA	ug/L	N/A	30	03-OCT-14
1,1-Dichloroethylene		<0.50	<0.50	RPD-NA	ug/L	N/A	30	03-OCT-14
1,1-Dichloropropene		<0.50	<0.50	RPD-NA	ug/L	N/A	30	03-OCT-14
1,2,3-Trichloropropane		<0.50	<0.50	RPD-NA	ug/L	N/A	30	03-OCT-14
1,2,3-Trichlorobenzene		<10	<10	RPD-NA	ug/L	N/A	30	03-OCT-14
1,2,4-Trichlorobenzene		<10	<10	RPD-NA	ug/L	N/A	30	03-OCT-14
1,2,4-Trimethylbenzene		<0.50	<0.50	RPD-NA	ug/L	N/A	30	03-OCT-14
1,2-Dibromo-3-chloropropane		<20	<20	RPD-NA	ug/L	N/A	30	03-OCT-14
1,2-Dibromoethane		<0.50	<0.50	RPD-NA	ug/L	N/A	30	03-OCT-14
1,2-Dichlorobenzene		<0.50	<0.50	RPD-NA	ug/L	N/A	30	03-OCT-14
1,2-Dichloroethane		<0.50	<0.50	RPD-NA	ug/L	N/A	30	03-OCT-14
1,2-Dichloropropane		<0.50	<0.50	RPD-NA	ug/L	N/A	30	03-OCT-14
1,3,5-Trimethylbenzene		<0.50	<0.50	RPD-NA	ug/L	N/A	30	03-OCT-14
1,3-Dichlorobenzene		<0.50	<0.50	RPD-NA	ug/L	N/A	30	03-OCT-14
1,3-Dichloropropane		<0.50	<0.50	RPD-NA	ug/L	N/A	30	03-OCT-14
1,4-Dichlorobenzene		<0.50	<0.50	RPD-NA	ug/L	N/A	30	03-OCT-14
2,2-Dichloropropane		<0.50	<0.50	RPD-NA	ug/L	N/A	30	03-OCT-14
2-Chlorotoluene		<20	<20	RPD-NA	ug/L	N/A	30	03-OCT-14
2-Hexanone		<20	<20	RPD-NA	ug/L	N/A	30	03-OCT-14
4-Chlorotoluene		<20	<20	RPD-NA	ug/L	N/A	30	03-OCT-14
Acetone		<20	<20	RPD-NA	ug/L	N/A	30	03-OCT-14
Benzene		<0.50	<0.50	RPD-NA	ug/L	N/A	30	03-OCT-14
Bromobenzene		<0.50	<0.50	RPD-NA	ug/L	N/A	30	03-OCT-14
Bromochloromethane		<0.50	<0.50	RPD-NA	ug/L	N/A	30	03-OCT-14
Bromodichloromethane		<2.0	<2.0	RPD-NA	ug/L	N/A	30	03-OCT-14
Bromoform		<1.0	<1.0	RPD-NA	ug/L	N/A	30	03-OCT-14
Bromomethane		<1.0	<1.0	RPD-NA	ug/L	N/A	30	03-OCT-14
Carbon Disulfide		<2.0	<2.0	RPD-NA	ug/L	N/A	30	03-OCT-14
Carbon tetrachloride		<0.50	<0.50		ug/L			03-OCT-14

Quality Control Report

Workorder: L1524406

Report Date: 06-OCT-14

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Client: SIREM
130 Research Lane Suite 2
Guelph ON N1G 5G3

Contact: Jeff Roberts

Test	Matrix	Reference	Result	Qualifier	Units	RPD	Limit	Analyzed
VOC-ROU1-HS-WT		Water						
Batch	R2971010							
WG1963525-4	DUP	WG1963525-3						
Carbon tetrachloride		<0.50	<0.50	RPD-NA	ug/L	N/A	30	03-OCT-14
Chlorobenzene		<0.50	<0.50	RPD-NA	ug/L	N/A	30	03-OCT-14
Chloroethane		<1.0	<1.0	RPD-NA	ug/L	N/A	30	03-OCT-14
Chloroform		<1.0	<1.0	RPD-NA	ug/L	N/A	30	03-OCT-14
Chloromethane		<1.0	<1.0	RPD-NA	ug/L	N/A	30	03-OCT-14
cis-1,2-Dichloroethylene		<0.50	<0.50	RPD-NA	ug/L	N/A	30	03-OCT-14
cis-1,3-Dichloropropene		<0.50	<0.50	RPD-NA	ug/L	N/A	30	03-OCT-14
Dibromochloromethane		<1.0	<1.0	RPD-NA	ug/L	N/A	30	03-OCT-14
Dibromomethane		<0.50	<0.50	RPD-NA	ug/L	N/A	30	03-OCT-14
Dichlorodifluoromethane		<1.0	<1.0	RPD-NA	ug/L	N/A	30	03-OCT-14
Dichloromethane		<5.0	<5.0	RPD-NA	ug/L	N/A	30	03-OCT-14
Ethyl Benzene		<0.50	<0.50	RPD-NA	ug/L	N/A	30	03-OCT-14
Hexachlorobutadiene		<5.0	<5.0	RPD-NA	ug/L	N/A	30	03-OCT-14
n-Hexane		<0.50	<0.50	RPD-NA	ug/L	N/A	30	03-OCT-14
Isopropylbenzene		<5.0	<5.0	RPD-NA	ug/L	N/A	30	03-OCT-14
Isopropyltoluene		<5.0	<5.0	RPD-NA	ug/L	N/A	30	03-OCT-14
m+p-Xylenes		<1.0	<1.0	RPD-NA	ug/L	N/A	30	03-OCT-14
Methyl Ethyl Ketone		<20	<20	RPD-NA	ug/L	N/A	30	03-OCT-14
Methyl Isobutyl Ketone		<20	<20	RPD-NA	ug/L	N/A	30	03-OCT-14
MTBE		<2.0	<2.0	RPD-NA	ug/L	N/A	30	03-OCT-14
Naphthalene		<10	<10	RPD-NA	ug/L	N/A	30	03-OCT-14
n-Butylbenzene		<5.0	<5.0	RPD-NA	ug/L	N/A	30	03-OCT-14
n-Propylbenzene		<5.0	<5.0	RPD-NA	ug/L	N/A	30	03-OCT-14
o-Xylene		<0.50	<0.50	RPD-NA	ug/L	N/A	30	03-OCT-14
sec-Butylbenzene		<5.0	<5.0	RPD-NA	ug/L	N/A	30	03-OCT-14
Styrene		<0.50	<0.50	RPD-NA	ug/L	N/A	30	03-OCT-14
tert-Butylbenzene		<5.0	<5.0	RPD-NA	ug/L	N/A	30	03-OCT-14
Tetrachloroethylene		<0.50	<0.50	RPD-NA	ug/L	N/A	30	03-OCT-14
Toluene		<0.50	<0.50	RPD-NA	ug/L	N/A	30	03-OCT-14
trans-1,2-Dichloroethylene		<0.50	<0.50	RPD-NA	ug/L	N/A	30	03-OCT-14
trans-1,3-Dichloropropene		<0.50	<0.50	RPD-NA	ug/L	N/A	30	03-OCT-14
Trichloroethylene		<0.50	<0.50	RPD-NA	ug/L	N/A	30	03-OCT-14
Trichlorofluoromethane		<1.0	<1.0		ug/L			03-OCT-14

Quality Control Report

Workorder: L1524406

Report Date: 06-OCT-14

Page 5 of 8

Client: SIREM
130 Research Lane Suite 2
Guelph ON N1G 5G3

Contact: Jeff Roberts

Test	Matrix	Reference	Result	Qualifier	Units	RPD	Limit	Analyzed
VOC-ROU1-HS-WT		Water						
Batch	R2971010							
WG1963525-4 DUP		WG1963525-3						
Trichlorofluoromethane		<1.0	<1.0	RPD-NA	ug/L	N/A	30	03-OCT-14
Vinyl chloride		1.27	1.34		ug/L	5.4	30	03-OCT-14
WG1963525-2 MB								
1,1,1,2-Tetrachloroethane			<0.50		ug/L		0.5	03-OCT-14
1,1,2,2-Tetrachloroethane			<0.50		ug/L		0.5	03-OCT-14
1,1,1-Trichloroethane			<0.50		ug/L		0.5	03-OCT-14
1,1,2-Trichloroethane			<0.50		ug/L		0.5	03-OCT-14
1,1-Dichloroethane			<0.50		ug/L		0.5	03-OCT-14
1,1-Dichloroethylene			<0.50		ug/L		0.5	03-OCT-14
1,1-Dichloropropene			<0.50		ug/L		0.5	03-OCT-14
1,2,3-Trichloropropane			<0.50		ug/L		0.5	03-OCT-14
1,2,3-Trichlorobenzene			<10		ug/L		10	03-OCT-14
1,2,4-Trichlorobenzene			<10		ug/L		10	03-OCT-14
1,2,4-Trimethylbenzene			<0.50		ug/L		0.5	03-OCT-14
1,2-Dibromo-3-chloropropane			<20		ug/L		20	03-OCT-14
1,2-Dibromoethane			<0.50		ug/L		0.5	03-OCT-14
1,2-Dichlorobenzene			<0.50		ug/L		0.5	03-OCT-14
1,2-Dichloroethane			<0.50		ug/L		0.5	03-OCT-14
1,2-Dichloropropane			<0.50		ug/L		0.5	03-OCT-14
1,3,5-Trimethylbenzene			<0.50		ug/L		0.5	03-OCT-14
1,3-Dichlorobenzene			<0.50		ug/L		0.5	03-OCT-14
1,3-Dichloropropane			<0.50		ug/L		0.5	03-OCT-14
1,4-Dichlorobenzene			<0.50		ug/L		0.5	03-OCT-14
2,2-Dichloropropane			<0.50		ug/L		0.5	03-OCT-14
2-Chlorotoluene			<20		ug/L		20	03-OCT-14
2-Hexanone			<20		ug/L		20	03-OCT-14
4-Chlorotoluene			<20		ug/L		20	03-OCT-14
Acetone			<20		ug/L		20	03-OCT-14
Benzene			<0.50		ug/L		0.5	03-OCT-14
Bromobenzene			<0.50		ug/L		0.5	03-OCT-14
Bromochloromethane			<0.50		ug/L		0.5	03-OCT-14
Bromodichloromethane			<2.0		ug/L		2	03-OCT-14
Bromoform			<1.0		ug/L		1	03-OCT-14
Bromomethane			<1.0		ug/L		1	03-OCT-14

Quality Control Report

Workorder: L1524406

Report Date: 06-OCT-14

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Client: SIREM
130 Research Lane Suite 2
Guelph ON N1G 5G3

Contact: Jeff Roberts

Test	Matrix	Reference	Result	Qualifier	Units	RPD	Limit	Analyzed
VOC-ROU1-HS-WT		Water						
Batch	R2971010							
WG1963525-2	MB							
Carbon Disulfide			<2.0		ug/L		2	03-OCT-14
Carbon tetrachloride			<0.50		ug/L		0.5	03-OCT-14
Chlorobenzene			<0.50		ug/L		0.5	03-OCT-14
Chloroethane			<1.0		ug/L		1	03-OCT-14
Chloroform			<1.0		ug/L		1	03-OCT-14
Chloromethane			<1.0		ug/L		1	03-OCT-14
cis-1,2-Dichloroethylene			<0.50		ug/L		0.5	03-OCT-14
cis-1,3-Dichloropropene			<0.50		ug/L		0.5	03-OCT-14
Dibromochloromethane			<1.0		ug/L		1	03-OCT-14
Dibromomethane			<0.50		ug/L		0.5	03-OCT-14
Dichlorodifluoromethane			<1.0		ug/L		1	03-OCT-14
Dichloromethane			<5.0		ug/L		5	03-OCT-14
Ethyl Benzene			<0.50		ug/L		0.5	03-OCT-14
Hexachlorobutadiene			<5.0		ug/L		5	03-OCT-14
n-Hexane			<0.50		ug/L		0.5	03-OCT-14
Isopropylbenzene			<5.0		ug/L		5	03-OCT-14
Isopropyltoluene			<5.0		ug/L		5	03-OCT-14
m+p-Xylenes			<1.0		ug/L		1	03-OCT-14
Methyl Ethyl Ketone			<20		ug/L		20	03-OCT-14
Methyl Isobutyl Ketone			<20		ug/L		20	03-OCT-14
MTBE			<2.0		ug/L		2	03-OCT-14
Naphthalene			<10		ug/L		10	03-OCT-14
n-Butylbenzene			<5.0		ug/L		5	03-OCT-14
n-Propylbenzene			<5.0		ug/L		5	03-OCT-14
o-Xylene			<0.50		ug/L		0.5	03-OCT-14
sec-Butylbenzene			<5.0		ug/L		5	03-OCT-14
Styrene			<0.50		ug/L		0.5	03-OCT-14
tert-Butylbenzene			<5.0		ug/L		5	03-OCT-14
Tetrachloroethylene			<0.50		ug/L		0.5	03-OCT-14
Toluene			<0.50		ug/L		0.5	03-OCT-14
trans-1,2-Dichloroethylene			<0.50		ug/L		0.5	03-OCT-14
trans-1,3-Dichloropropene			<0.50		ug/L		0.5	03-OCT-14
Trichloroethylene			<0.50		ug/L		0.5	03-OCT-14

Quality Control Report

Workorder: L1524406

Report Date: 06-OCT-14

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Client: SIREM
130 Research Lane Suite 2
Guelph ON N1G 5G3

Contact: Jeff Roberts

Test	Matrix	Reference	Result	Qualifier	Units	RPD	Limit	Analyzed
VOC-ROU1-HS-WT		Water						
Batch R2971010								
WG1963525-2 MB								
Trichlorofluoromethane			<1.0		ug/L		1	03-OCT-14
Vinyl chloride			<0.50		ug/L		0.5	03-OCT-14
Surrogate: 1,4-Difluorobenzene			97.6		%		70-130	03-OCT-14
Surrogate: 4-Bromofluorobenzene			90.5		%		70-130	03-OCT-14

Quality Control Report

Workorder: L1524406

Report Date: 06-OCT-14

Client: SIREM
130 Research Lane Suite 2
Guelph ON N1G 5G3
Contact: Jeff Roberts

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Legend:

Limit	ALS Control Limit (Data Quality Objectives)
DUP	Duplicate
RPD	Relative Percent Difference
N/A	Not Available
LCS	Laboratory Control Sample
SRM	Standard Reference Material
MS	Matrix Spike
MSD	Matrix Spike Duplicate
ADE	Average Desorption Efficiency
MB	Method Blank
IRM	Internal Reference Material
CRM	Certified Reference Material
CCV	Continuing Calibration Verification
CVS	Calibration Verification Standard
LCSD	Laboratory Control Sample Duplicate

Sample Parameter Qualifier Definitions:

Qualifier	Description
RPD-NA	Relative Percent Difference Not Available due to result(s) being less than detection limit.

Hold Time Exceedances:

All test results reported with this submission were conducted within ALS recommended hold times.

ALS recommended hold times may vary by province. They are assigned to meet known provincial and/or federal government requirements. In the absence of regulatory hold times, ALS establishes recommendations based on guidelines published by the US EPA, APHA Standard Methods, or Environment Canada (where available). For more information, please contact ALS.

The ALS Quality Control Report is provided to ALS clients upon request. ALS includes comprehensive QC checks with every analysis to ensure our high standards of quality are met. Each QC result has a known or expected target value, which is compared against pre-determined data quality objectives to provide confidence in the accuracy of associated test results.

Please note that this report may contain QC results from anonymous Sample Duplicates and Matrix Spikes that do not originate from this Work Order.



Chain of Custody (COC) / Analytical Request Form

Canada Toll Free: 1 800 668 9878



L1524406-COFC

COC Number: 14 -

Page 1 of 1

www.alsglobal.com

[illegible]

REFER TO BACK PAGE FOR ALS LOCATIONS AND SAMPLING INFORMATION

Failure to complete all portions of this form may delay analysis. Please fill in this form LEGIBLY. By the use of this form the user acknowledges and agrees with the Terms and Conditions as specified on the back page of the white-report copy.

1. If any water samples are taken from a **Regulated Drinking Water (DW) System**, please submit using an **Authorized DW COC form**.

WHITE - LABORATORY COPY YELLOW - CLIENT COPY

NA-EM-0126a v09 Front04 January 2011

APPENDIX C: SGS Environmental Laboratory Reports

**SGS Canada Inc.**

P.O. Box 4300 - 185 Concession St.
 Lakefield - Ontario - K0L 2H0
 Phone: 705-652-2000 FAX: 705-652-6365

30-September-2014

SiREM Laboratory

Attn : Jeff Roberts

130 Research Lane, Suite 2, Guelph
 , N1G 5G3
 Phone: 519-822-2265, Fax:519-822-3151

Date Rec. : 26 September 2014
LR Report: CA13678-SEP14
Reference: Rhode Island

Copy: #1

CERTIFICATE OF ANALYSIS

Final Report

Analysis	3: Analysis Approval Date	4: Analysis Approval Time	5: RI-250914-M1	6: RI-250914-M2
Sample Date & Time			25-Sep-14	25-Sep-14
Temperature Upon Receipt [°C]			12.0	12.0
Silver (dissolved) [mg/L]	29-Sep-14	14:51	< 0.000002	< 0.000002
Aluminum (dissolved) [mg/L]	30-Sep-14	15:34	< 0.01	< 0.01
Arsenic (dissolved) [mg/L]	29-Sep-14	14:52	0.0162	0.0137
Barium (dissolved) [mg/L]	29-Sep-14	14:51	0.0965	0.103
Beryllium (dissolved) [mg/L]	29-Sep-14	14:51	< 0.000007	< 0.000007
Boron (dissolved) [mg/L]	29-Sep-14	14:51	0.0887	0.0846
Bismuth (dissolved) [mg/L]	29-Sep-14	14:51	0.000026	< 0.000007
Calcium (dissolved) [mg/L]	30-Sep-14	15:34	39.2	35.2
Cadmium (dissolved) [mg/L]	29-Sep-14	14:51	0.000062	0.000010
Cobalt (dissolved) [mg/L]	29-Sep-14	14:51	0.000598	0.000333
Chromium (dissolved) [mg/L]	29-Sep-14	14:51	0.00239	0.00182
Copper (dissolved) [mg/L]	29-Sep-14	14:51	0.00074	0.00023
Iron (dissolved) [mg/L]	30-Sep-14	15:34	7.39	7.56
Potassium (dissolved) [mg/L]	30-Sep-14	15:34	10.1	9.77
Lithium (dissolved) [mg/L]	29-Sep-14	14:51	0.00535	0.00485
Magnesium (dissolved) [mg/L]	30-Sep-14	15:34	4.70	4.67
Manganese (dissolved) [mg/L]	29-Sep-14	14:51	0.425	0.404
Molybdenum (dissolved) [mg/L]	29-Sep-14	14:51	0.00362	0.00290
Sodium (dissolved) [mg/L]	30-Sep-14	15:34	22.8	23.2
Nickel (dissolved) [mg/L]	29-Sep-14	14:51	0.0043	0.0042
Lead (dissolved) [mg/L]	29-Sep-14	14:51	0.00013	0.00012
Antimony (dissolved) [mg/L]	29-Sep-14	14:51	0.0006	0.0005
Selenium (dissolved) [mg/L]	29-Sep-14	14:51	< 0.001	< 0.001
Tin (dissolved) [mg/L]	29-Sep-14	14:51	0.00020	0.00016
Strontium (dissolved) [mg/L]	30-Sep-14	15:34	0.176	0.170
Titanium (dissolved) [mg/L]	29-Sep-14	14:51	0.00051	0.00071
Thallium (dissolved) [mg/L]	29-Sep-14	14:51	0.000069	0.000059
Uranium (dissolved) [mg/L]	29-Sep-14	14:51	0.000200	0.000135
Vanadium (dissolved) [mg/L]	29-Sep-14	14:51	0.00124	0.00096

SGS Canada Inc.

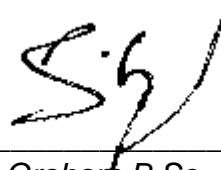
P.O. Box 4300 - 185 Concession St.

Lakefield - Ontario - KOL 2H0

Phone: 705-652-2000 FAX: 705-652-6365

LR Report : CA13678-SEP14

Analysis	3: Analysis Approval Date	4: Analysis Approval Time	5: RI-250914-M1	6: RI-250914-M2
Tungsten (dissolved) [mg/L]	29-Sep-14	14:51	0.00021	0.00014
Yttrium (dissolved) [mg/L]	29-Sep-14	14:51	0.000625	0.000743
Zinc (dissolved) [mg/L]	30-Sep-14	15:34	0.015	0.004



Brian Graham B.Sc.
Project Specialist
Environmental Services, Analytical

**SGS Canada Inc.**

P.O. Box 4300 - 185 Concession St.
 Lakefield - Ontario - K0L 2H0
 Phone: 705-652-2000 FAX: 705-652-6365

SiREM Laboratory

Attn : Jeff Roberts

130 Research Lane, Suite 2, Guelph
 , N1G 5G3
 Phone: 519-822-2265, Fax:519-822-3151

04-December-2014

Date Rec. : 27 November 2014
LR Report: CA13542-NOV14
Reference: Rhode Island

Copy: #1

CERTIFICATE OF ANALYSIS

Final Report

Analysis	3: Analysis Approval Date	4: Analysis Approval Time	5: RI-261114-07	6: RI-261114-08
Sample Date & Time			26-Nov-14	26-Nov-14
Temperature Upon Receipt [°			13.0	13.0
Silver (dissolved) [mg/L]	03-Dec-14	13:09	< 0.000002	< 0.000002
Aluminum (dissolved) [mg/L]	28-Nov-14	15:11	< 0.01	< 0.01
Arsenic (dissolved) [mg/L]	03-Dec-14	13:09	0.0012	0.0012
Barium (dissolved) [mg/L]	03-Dec-14	13:09	0.122	0.140
Beryllium (dissolved) [mg/L]	03-Dec-14	13:09	0.000008	0.000011
Boron (dissolved) [mg/L]	03-Dec-14	13:09	0.100	0.0928
Bismuth (dissolved) [mg/L]	03-Dec-14	13:09	0.000016	0.000012
Calcium (dissolved) [mg/L]	28-Nov-14	15:11	40.8	48.0
Cadmium (dissolved) [mg/L]	03-Dec-14	13:10	0.000497	0.000578
Cobalt (dissolved) [mg/L]	03-Dec-14	13:10	0.00664	0.0100
Chromium (dissolved) [mg/L]	03-Dec-14	13:10	0.00032	0.00030
Copper (dissolved) [mg/L]	03-Dec-14	13:10	0.0122	0.0145
Iron (dissolved) [mg/L]	28-Nov-14	15:11	0.082	0.076
Potassium (dissolved) [mg/L]	28-Nov-14	15:11	10.7	10.8
Lithium (dissolved) [mg/L]	03-Dec-14	13:10	0.00213	0.00215
Magnesium (dissolved) [mg/L]	28-Nov-14	15:11	5.25	5.43
Manganese (dissolved) [mg/L]	03-Dec-14	13:10	0.367	0.490
Molybdenum (dissolved) [mg/L]	03-Dec-14	13:10	0.00385	0.00322
Sodium (dissolved) [mg/L]	28-Nov-14	15:11	26.7	25.9
Nickel (dissolved) [mg/L]	03-Dec-14	13:10	0.0093	0.0097
Lead (dissolved) [mg/L]	03-Dec-14	13:10	0.00030	0.00021
Antimony (dissolved) [mg/L]	03-Dec-14	13:10	0.0011	0.0012
Selenium (dissolved) [mg/L]	03-Dec-14	13:10	< 0.001	< 0.001
Tin (dissolved) [mg/L]	03-Dec-14	13:10	0.00003	0.00002
Strontium (dissolved) [mg/L]	28-Nov-14	15:11	0.184	0.203
Titanium (dissolved) [mg/L]	03-Dec-14	13:10	0.00013	0.00008
Thallium (dissolved) [mg/L]	03-Dec-14	13:10	0.000053	0.000080

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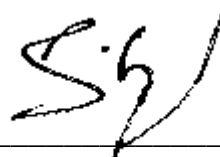
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Phone: 705-652-2000 FAX: 705-652-6365

LR Report : CA13542-NOV14

Analysis	3: Analysis Approval Date	4: Analysis Approval Time	5: RI-261114-07	6: RI-261114-08
Uranium (dissolved) [mg/L]	03-Dec-14	13:10	0.000013	0.000020
Vanadium (dissolved) [mg/L]	03-Dec-14	13:10	0.00031	0.00034
Tungsten (dissolved) [mg/L]	03-Dec-14	13:10	< 0.00002	< 0.00002
Yttrium (dissolved) [mg/L]	03-Dec-14	13:10	0.000728	0.000398
Zinc (dissolved) [mg/L]	28-Nov-14	15:11	0.028	0.030



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SiREM Laboratory

Attn : Jeff Roberts

130 Research Lane, Suite 2, Guelph

, N1G 5G3

Phone: 519-822-2265, Fax:519-822-3151

07-May-2015

Date Rec. : 01 May 2015

LR Report: CA13051-MAY15

Copy: #1

CERTIFICATE OF ANALYSIS

Final Report

Analysis	3: Analysis Approval Date	4: Analysis Approval Time	5: RI-300415-1	6: RI-300415-2	7: RI-300415-3	8: RI-300415-4	9: RI-300415-5	10: RI-300415-6
Sample Date & Time			NA	NA	NA	NA	NA	NA
Temperature Upon Receipt [°C]	---	---	4.0	4.0	4.0	4.0	4.0	4.0
Silver (dissolved) [mg/L]	06-May-15	09:51	0.000013	0.000007	0.000006	0.000002	0.000005	< 0.000002
Aluminum (dissolved) [mg/L]	05-May-15	09:33	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Arsenic (dissolved) [mg/L]	06-May-15	09:51	0.0101	0.0081	0.0062	0.0042	0.0095	0.0138
Barium (dissolved) [mg/L]	06-May-15	09:51	0.276	0.265	0.0882	0.101	0.165	0.168
Beryllium (dissolved) [mg/L]	06-May-15	09:51	0.000053	0.000050	0.000022	0.000023	0.000027	0.000030
Boron (dissolved) [mg/L]	06-May-15	09:51	0.104	0.104	0.0983	0.0989	0.120	0.119
Bismuth (dissolved) [mg/L]	06-May-15	09:51	0.000020	0.000028	< 0.000007	0.000011	0.000020	0.000013
Calcium (dissolved) [mg/L]	05-May-15	09:33	44.1	44.3	44.3	47.2	51.8	53.3
Cadmium (dissolved) [mg/L]	06-May-15	09:51	0.000066	0.000028	0.000003	0.000005	0.000005	0.000009
Cobalt (dissolved) [mg/L]	06-May-15	09:51	0.00247	0.00134	0.000492	0.000273	0.000723	0.000760
Chromium (dissolved) [mg/L]	06-May-15	09:51	0.00082	0.00052	0.00097	0.00094	0.00189	0.00170
Copper (dissolved) [mg/L]	06-May-15	09:51	0.00142	0.00043	0.00023	0.00014	0.00043	0.00039
Iron (dissolved) [mg/L]	05-May-15	09:33	13.7	13.4	0.31	0.94	0.60	0.36
Potassium (dissolved) [mg/L]	05-May-15	09:33	12.6	12.1	9.32	9.98	22.5	22.1
Lithium (dissolved) [mg/L]	06-May-15	09:51	0.00444	0.00470	0.00156	0.00202	0.00272	0.00250
Magnesium (dissolved) [mg/L]	05-May-15	09:33	7.01	7.07	59.2	60.5	106	102
Manganese (dissolved) [mg/L]	06-May-15	09:51	1.84	1.68	0.259	0.358	0.504	0.431
Molybdenum (dissolved) [mg/L]	06-May-15	09:51	0.00225	0.00150	0.00014	0.00012	0.00014	0.00013
Sodium (dissolved) [mg/L]	05-May-15	09:33	118	119	76.5	81.0	28.8	28.7
Nickel (dissolved) [mg/L]	06-May-15	09:51	0.0077	0.0061	0.0033	0.0032	0.0040	0.0044



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LR Report :

CA13051-MAY15

Analysis	3: Analysis Approval Date	4: Analysis Approval Time	5: RI-300415-1	6: RI-300415-2	7: RI-300415-3	8: RI-300415-4	9: RI-300415-5	10: RI-300415-6
Lead (dissolved) [mg/L]	06-May-15	09:51	0.00031	0.00019	0.00023	0.00011	0.00029	0.00023
Antimony (dissolved) [mg/L]	06-May-15	09:51	0.0002	0.0002	< 0.0002	< 0.0002	0.0002	0.0003
Selenium (dissolved) [mg/L]	06-May-15	09:51	< 0.001	< 0.001	0.001	< 0.001	< 0.001	0.001
Tin (dissolved) [mg/L]	06-May-15	09:51	0.00007	0.00009	0.00025	0.00013	0.00024	0.00045
Strontium (dissolved) [mg/L]	05-May-15	09:33	0.271	0.281	0.217	0.247	0.284	0.281
Titanium (dissolved) [mg/L]	06-May-15	09:51	0.00037	0.00026	0.00135	0.00136	0.00897	0.00807
Thallium (dissolved) [mg/L]	06-May-15	09:51	< 0.000005	< 0.000005	< 0.000005	< 0.000005	< 0.000005	< 0.000005
Uranium (dissolved) [mg/L]	06-May-15	09:51	0.000023	0.000028	0.000005	0.000006	0.000006	0.000007
Vanadium (dissolved) [mg/L]	06-May-15	09:51	0.00042	0.00034	0.00325	0.00193	0.00770	0.00673
Tungsten (dissolved) [mg/L]	06-May-15	09:51	< 0.00002	< 0.00002	0.00113	0.00085	0.00032	0.00053
Yttrium (dissolved) [mg/L]	06-May-15	09:51	0.00131	0.00132	0.00605	0.00390	0.00634	0.00844
Zinc (dissolved) [mg/L]	05-May-15	09:33	0.04	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02

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LR Report :

CA13051-MAY15

Quality Control Report

Inorganic Analysis												
Parameter	Reporting Limit	Unit	Method Blank		RPD		LCS / Spike Blank			Matrix Spike / Reference Material		
							Acceptance Criteria	Spike Recovery (%)	Recovery Limits (%)		Spike Recovery (%)	Recovery Limits (%)
					%	Low			High	Low		High
Metals in aqueous samples - ICP-MS - QCBatchID: EMS0009-MAY15												
Antimony (dissolved)	0.0002	mg/L	<0.0002		8	20	97	90	110	104	70	130
Arsenic (dissolved)	0.0002	mg/L	<0.0002		2	20	106	90	110	98	70	130
Barium (dissolved)	0.00002	mg/L	<0.00002		3	20	104	90	110	NV	70	130
Beryllium (dissolved)	0.000007	mg/L	<0.000007		ND	20	102	90	110	96	70	130
Bismuth (dissolved)	0.000007	mg/L	<0.000007		10	20	103	90	110	NV	70	130
Boron (dissolved)	0.0002	mg/L	<0.0002		3	20	107	90	110	NV	70	130
Cadmium (dissolved)	0.000003	mg/L	<0.000003		ND	20	107	90	110	97	70	130
Chromium (dissolved)	0.00003	mg/L	<0.00003		1	20	104	90	110	108	70	130
Cobalt (dissolved)	0.000004	mg/L	<0.000004		3	20	107	90	110	95	70	130
Copper (dissolved)	0.00002	mg/L	<0.00002		20	20	105	90	110	98	70	130
Lead (dissolved)	0.00001	mg/L	<0.00001		ND	20	105	90	110	92	70	130
Lithium (dissolved)	0.000006	mg/L	<0.000006		1	20	103	90	110	NV	70	130
Manganese (dissolved)	0.00001	mg/L	<0.00001		2	20	101	90	110	91	70	130
Molybdenum (dissolved)	0.00001	mg/L	<0.00001		1	20	101	90	110	93	70	130
Nickel (dissolved)	0.0001	mg/L	<0.0001		2	20	108	90	110	94	70	130
Selenium (dissolved)	0.001	mg/L	<0.001		12	20	100	90	110	100	70	130
Silver (dissolved)	0.000002	mg/L	<0.000002		ND	20	106	90	110	108	70	130
Thallium (dissolved)	0.000005	mg/L	<0.000005		ND	20	108	90	110	92	70	130
Tin (dissolved)	0.00001	mg/L	<0.00001		7	20	107	90	110	NV	70	130
Titanium (dissolved)	0.00005	mg/L	<0.00005		4	20	101	90	110	NV	70	130
Tungsten (dissolved)	0.00002	mg/L	<0.00002		4	20	105	90	110	NV	70	130
Uranium (dissolved)	0.000002	mg/L	<0.000002		ND	20	105	90	110	95	70	130
Vanadium (dissolved)	0.00001	mg/L	<0.00001		7	20	105	90	110	96	70	130
Yttrium (dissolved)	0.000002	mg/L	<0.000002		2	20	106	90	110	NV	70	130
Metals in aqueous samples - ICP-OES - QCBatchID: ESG0006-MAY15												
Aluminum (dissolved)	0.1	mg/L	<0.01		ND	20	103	90	110	103	70	130
Calcium (dissolved)	0.02	mg/L	<0.02		NV	20	104	90	110	NV	70	130
Iron (dissolved)	0.02	mg/L	<0.002		1	20	103	90	110	NV	70	130
Magnesium (dissolved)	0.003	mg/L	<0.003		1	20	101	90	110	NV	70	130
Potassium (dissolved)	0.002	mg/L	<0.002		3	20	104	90	110	NV	70	130
Sodium (dissolved)	0.01	mg/L	<0.01		NV	20	119	90	110	NV	70	130
Strontium (dissolved)	0.0002	mg/L	<0.0002		1	20	102	90	110	NV	70	130
Zinc (dissolved)	0.02	mg/L	<0.002		ND	20	102	90	110	99	70	130

APPENDIX D: Henry's Law Calculation

The following Henry's Law calculation was used to convert aqueous concentrations (Table 2) to total mmoles of each analyte per microcosm bottle (Figures 2 to 6):

$$Total\ mmoles = \frac{C_{liq} \cdot (V_{liq} + H \cdot V_{gas})}{Molecular\ Weight\ (\frac{mg}{mmol})}$$

Where

C_{liq} = liquid concentration (mg/L)

V_{liq} = liquid volume (0.225 L) per bottle

V_{gas} = headspace volume (0.025 L) per bottle

H = Henry's Law constant (dimensionless)

The Henry's Law constants used are summarized in the table below.

Analyte	Henry's Law Constant ^a (dimensionless)
Tetrachloroethene	0.602
Trichloroethene	0.417
cis-1,2-Dichloroethene	0.184
Vinyl chloride	1.08
Ethene	8.78
Ethane	20.5
Methane	27.3
1,2-Dichlorobenzene	0.064
1,4-Dichlorobenzene	0.130
1,3-Dichlorobenzene	0.117
Chlorobenzene	0.161
2-Chlorotoluene	0.135
Benzene	0.222
Toluene	0.266
Ethyl Benzene	0.358
o-Xylene	0.199

^a Source: Montgomery, J.H. 2000. *Groundwater Chemicals Desk Reference, Third Edition*. CRC Press LLC, Boca Raton, FL.

Table F-1
Corrective Measures Study - Pre Design Investigation Groundwater Results - September 2014
BASF - 180 Mill Street
Cranston, RI

				Sample ID Sample Date sample_type_code Depth Interval sys_sample_code	SB301 9/12/2014 N 6-16 ft DUPLICATE_WG_09122014	SB301 9/12/2014 N 6-16 ft SB-301-S_09122014	SB301 9/12/2014 N 16-26 ft SB-301-D_09122014	SB302 9/12/2014 N 6-16 ft SB-302-S_09122014	SB302 9/12/2014 N 16-26 ft SB-302-D_09122014	SB303 9/12/2014 N 6-16 ft SB-303-S_09122014	SB303 9/12/2014 N 16-26 ft SB-303-D_09122014	SB304 9/12/2014 N 6-16 ft SB-304-S_09122014	SB304 9/12/2014 N 16-26 ft SB-304-D_09122014
chemical_name	Media Protection Standards	GB Criteria	report_result_unit										
1,1,1,2-TETRACHLOROETHANE			ug/l	< 100 U	< 500 U	< 500 U	< 50.0 U	< 250 U	< 10.0 U	< 250 U	< 250 U	< 250 U	< 250 U
1,1,1-TRICHLOROETHANE (TCA)		3100	ug/l	< 100 U	< 500 U	< 500 U	< 50.0 U	< 250 U	< 10.0 U	< 250 U	< 250 U	< 250 U	< 250 U
1,1,2,2-TETRACHLOROETHANE			ug/l	< 50.0 U	< 250 U	< 250 U	< 25.0 U	< 125 U	< 5.0 U	< 125 U	< 125 U	< 125 U	< 125 U
1,1,2-TRICHLORO-1,2,2-TRIFLUOROETHANE			ug/l	< 100 U	< 500 U	< 500 U	< 50.0 U	< 250 U	< 10.0 U	< 250 U	< 250 U	< 250 U	< 250 U
1,1,2-TRICHLOROETHANE		3100	ug/l	< 100 U	< 500 U	< 500 U	< 50.0 U	< 250 U	< 10.0 U	< 250 U	< 250 U	< 250 U	< 250 U
1,1-DICHLOROETHANE			ug/l	< 100 U	< 500 U	< 500 U	< 50.0 U	< 250 U	< 10.0 U	< 250 U	< 250 U	< 250 U	< 250 U
1,1-DICHLOROETHENE		7	ug/l	< 100 U	< 500 U	< 500 U	< 50.0 U	< 250 U	< 10.0 U	< 250 U	< 250 U	< 250 U	< 250 U
1,1-DICHLOROPROPENE			ug/l	< 100 U	< 500 U	< 500 U	< 50.0 U	< 250 U	< 10.0 U	< 250 U	< 250 U	< 250 U	< 250 U
1,2,3-TRICHLOROBENZENE			ug/l	< 100 U	< 500 U	< 500 U	< 50.0 U	< 250 U	< 10.0 U	< 250 U	< 250 U	< 250 U	< 250 U
1,2,3-TRICHLOROPROPANE			ug/l	< 100 U	< 500 U	< 500 U	< 50.0 U	< 250 U	< 10.0 U	< 250 U	< 250 U	< 250 U	< 250 U
1,2,4-TRICHLOROBENZENE			ug/l	< 100 U	< 500 U	< 500 U	< 50.0 U	< 250 U	< 10.0 U	< 250 U	< 250 U	< 250 U	< 250 U
1,2,4-TRIMETHYLBENZENE			ug/l	< 100 U	< 500 U	< 500 U	< 50.0 U	< 250 U	< 10.0 U	< 250 U	< 250 U	< 250 U	< 250 U
1,2-DIBROMO-3-CHLOROPROPANE (DBCP)		2	ug/l	< 200 U	< 1000 U	< 1000 U	< 100 U	< 500 U	< 20.0 U	< 500 U	< 500 U	< 500 U	< 500 U
1,2-DIBROMOETHANE (EDB)			ug/l	< 50.0 U	< 250 U	< 250 U	< 25.0 U	< 125 U	< 5.0 U	< 125 U	< 125 U	< 125 U	< 125 U
1,2-DICHLOROBENZENE	94		ug/l	< 100 U	< 500 U	< 500 U	1500	4560	17.3	< 250 U	< 250 U	< 250 U	3560
1,2-DICHLOROETHANE		110	ug/l	< 100 U	< 500 U	< 500 U	< 50.0 U	< 250 U	< 10.0 U	< 250 U	< 250 U	< 250 U	< 250 U
1,2-DICHLOROPROPANE		3000	ug/l	< 100 U	< 500 U	< 500 U	< 50.0 U	< 250 U	< 10.0 U	< 250 U	< 250 U	< 250 U	< 250 U
1,3,5- TRICHLOROBENZENE			ug/l	< 100 U	< 500 U	< 500 U	< 50.0 U	< 250 U	< 10.0 U	< 250 U	< 250 U	< 250 U	< 250 U
1,3,5-TRIMETHYLBENZENE			ug/l	< 100 U	< 500 U	< 500 U	< 50.0 U	< 250 U	< 10.0 U	< 250 U	< 250 U	< 250 U	< 250 U
1,3-DICHLOROBENZENE			ug/l	< 100 U	< 500 U	< 500 U	< 50.0 U	< 250 U	< 10.0 U	< 250 U	< 250 U	< 250 U	< 250 U
1,3-DICHLOROPROPANE		3000	ug/l	< 100 U	< 500 U	< 500 U	< 50.0 U	< 250 U	< 10.0 U	< 250 U	< 250 U	< 250 U	< 250 U
1,4-DICHLOROBENZENE			ug/l	< 100 U	< 500 U	< 500 U	< 50.0 U	< 250 U	< 10.0 U	< 250 U	< 250 U	< 250 U	< 250 U
1,4-DIOXANE			ug/l	< 2000 U	< 10000 U	< 10000 U	< 1000 U	< 5000 U	< 200 U	< 5000 U	< 5000 U	< 5000 U	< 5000 U
2,2-DICHLOROPROPANE		3000	ug/l	< 100 U	< 500 U	< 500 U	< 50.0 U	< 250 U	< 10.0 U	< 250 U	< 250 U	< 250 U	< 250 U
2-BUTANONE (MEK)			ug/l	< 1000 U	< 5000 U	< 5000 U	< 500 U	< 2500 U	< 100 U	< 2500 U	< 2500 U	< 2500 U	< 2500 U
2-CHLOROTOLUENE	1500		ug/l	23600 E	20600	41000	9010 E	28400 E	1640 E	11700	1880	29200	29200 U
2-HEXANONE			ug/l	< 1000 U	< 5000 U	< 5000 U	< 500 U	< 2500 U	< 100 U	< 2500 U	< 2500 U	< 2500 U	< 2500 U
2-PHENYLBUTANE			ug/l	< 100 U	< 500 U	< 500 U	< 50.0 U	< 250 U	< 10.0 U	< 250 U	< 250 U	< 250 U	< 250 U
4-CHLOROTOLUENE			ug/l	1200	1340	2910	584	1960	83.3	665	< 250 U	2070	
4-METHYL-2-PENTANONE (MIBK)			ug/l	< 1000 U	< 5000 U	< 5000 U	< 500 U	< 2500 U	< 100 U	< 2500 U	< 2500 U	< 2500 U	< 2500 U
ACETONE			ug/l	< 1000 U	< 5000 U	< 5000 U	< 500 U	< 2500 U	< 100 U	< 2500 U	< 2500 U	< 2500 U	< 2500 U
ACRYLONITRILE			ug/l	< 50.0 U	< 250 U	< 250 U	< 25.0 U	< 125 U	< 5.0 U	< 125 U	< 125 U	< 125 U	< 125 U
BENZENE		140	ug/l	< 100 U	< 500 U	< 500 U	< 50.0 U	< 250 U	< 10.0 U	< 250 U	< 250 U	< 250 U	275
BROMOBENZENE			ug/l	< 100 U	< 500 U	< 500 U	499	692	< 10.0 U	< 250 U	< 250 U	< 250 U	3570
BROMODICHLOROMETHANE			ug/l	< 50.0 U	< 250 U	< 250 U	< 25.0 U	< 125 U	< 5.0 U	< 125 U	< 125 U	< 125 U	< 125 U
BROMOFORM			ug/l	< 100 U	< 500 U	< 500 U	< 50.0 U	< 250 U	< 10.0 U	< 250 U	< 250 U	< 250 U	< 250 U
BROMOMETHANE			ug/l	< 200 U	< 1000 U	< 1000 U	< 100 U	< 500 U	< 20.0 U	< 500 U	< 500 U	< 500 U	< 500 U
CARBON DISULFIDE			ug/l	< 200 U	< 1000 U	< 1000 U	< 100 U	< 500 U	< 20.0 U	< 500 U	< 500 U	< 500 U	< 500 U
CARBON TETRACHLORIDE		70	ug/l	< 100 U	< 500 U	< 500 U	< 50.0 U	< 250 U	< 10.0 U	< 250 U	< 250 U	< 250 U	< 250 U
CHLOROBENZENE	1700	3200	ug/l	< 100 U	< 500 U	< 500 U	1710	2290	22.9	< 250 U	820	14100	
CHLOROBROMOMETHANE			ug/l	< 100 U	< 500 U	< 500 U	< 50.0 U	< 250 U	< 10.0 U	< 250 U	< 250 U	< 250 U	< 250 U
CHLOROETHANE			ug/l	< 200 U	< 1000 U	< 1000 U	< 100 U	< 500 U	< 20.0 U	< 500 U	< 500 U	< 500 U	< 500 U
CHLOROFORM			ug/l	< 100 U	< 500 U	< 500 U	< 50.0 U	< 250 U	< 10.0 U	< 250 U	< 250 U	< 250 U	< 250 U
CHLOROMETHANE			ug/l	< 200 U	< 1000 U	< 1000 U	< 100 U	< 500 U	< 20.0 U	< 500 U	< 500 U	< 500 U	< 500 U
CIS-1,2-DICHLOROETHENE		2400	ug/l	< 100 U	< 500 U	< 500 U	< 50.0 U	< 250 U	< 10.0 U	< 250 U	< 250 U	< 250 U	< 250 U
CIS-1,3-DICHLOROPROPENE			ug/l	< 50.0 U	< 250 U	< 250 U	< 25.0 U	< 125 U	< 5.0 U	< 125 U	< 125 U	< 125 U	< 125 U
CYMENE			ug/l	< 100 U	< 500 U	< 500 U	< 50.0 U	< 250 U	< 10.0 U	< 250 U	< 250 U	< 250 U	< 250 U
DIBROMOCHLOROMETHANE			ug/l	< 50.0 U	< 250 U	< 250 U	< 25.0 U	< 125 U	< 5.0 U	< 125 U	< 125 U	< 125 U	< 125 U
DIBROMOMETHANE			ug/l	< 100 U	< 500 U	< 500 U	< 50.0 U	< 250 U	< 10.0 U	< 250 U	< 250 U	< 250 U	< 250 U
DICHLORODIFLUOROMETHANE			ug/l	< 200 U	< 1000 U	< 1000 U	< 100 U	< 500 U	< 20.0 U	< 500 U	< 500 U	< 500 U	< 500 U
DIETHYL ETHER			ug/l	< 100 U	< 500 U	< 500 U	< 50.0 U	< 250 U	< 10.0 U	< 250 U	< 250 U	< 250 U	< 250 U
DIISOPROPYL ETHER			ug/l	< 100 U	< 500 U	< 500 U	< 50.0 U	< 250 U	< 10.0 U	< 250 U	< 250 U	< 250 U	< 250 U
ETHANOL			ug/l	< 40000 U	< 200000 U	< 200000 U	< 20000 U	< 100000 U	< 4000 U	< 100000 U	< 100000 U	< 100000 U	< 100000 U
ETHYLBENZENE		1600	ug/l	133	< 500 U	< 500 U	216	962	14.2	252	270	708	
Ethyltertiarybutylether			ug/l	< 100 U	< 500 U	< 500 U	< 50.0 U	< 250 U	< 10.0 U	< 250 U	< 250 U	< 250 U	< 250 U
HEXACHLORO-1,3-BUTADIENE			ug/l	< 50.0 U	< 250 U	< 250 U	< 25.0 U	< 125 U	< 5.0 U	< 125 U	< 125 U	< 125 U	< 125 U
ISOPROPYLBENZENE			ug/l	< 100 U	< 500 U	< 500 U	< 50.0 U	< 250 U	< 10.0 U	< 250 U	< 250 U	< 250 U	< 250 U
METHYL TERT-BUTYL ETHER		5000	ug/l	< 100 U	< 500 U	< 500 U	< 50.0 U	< 250 U	< 10.0 U	< 250 U	< 250 U	< 250 U	< 250 U
METHYLENE CHLORIDE			ug/l	< 200 U	< 1000 U	< 1000 U	< 100 U	< 500 U	< 20.0 U	< 500 U	< 500 U	< 500 U	< 500 U
m-Xylene & p-Xylene			ug/l	273	< 1000 U	< 1000 U	652	2870	31.7	505	558	1840	
NAPHTHALENE			ug/l	< 100 U	< 500 U	< 500 U	< 50.0 U	< 250 U	< 10.0 U	< 250 U	< 250 U	< 250 U	< 250 U
N-BUTYLBENZENE			ug/l	< 100 U	< 500 U	< 500 U	< 50.0 U	< 250 U	< 10.0 U	< 250 U	< 250 U	< 250 U	< 250 U
N-PROPYLBENZENE			ug/l	< 100 U	< 500 U	< 500 U	< 50.0 U	< 250 U	< 10.0 U	< 250 U	< 250 U	< 250 U	< 250 U

Table F-1
Corrective Measures Study - Pre Design Investigation Groundwater Results - September 2014
BASF - 180 Mill Street
Cranston, RI

			Sample ID Sample Date sample_type_code Depth Interval sys_sample_code	SB301 9/12/2014 N 6-16 ft DUPLICATE_WG_09122014	SB301 9/12/2014 N 6-16 ft SB-301-S_09122014	SB301 9/12/2014 N 16-26 ft SB-301-D_09122014	SB302 9/12/2014 N 6-16 ft SB-302-S_09122014	SB302 9/12/2014 N 16-26 ft SB-302-D_09122014	SB303 9/12/2014 N 6-16 ft SB-303-S_09122014	SB303 9/12/2014 N 16-26 ft SB-303-D_09122014	SB304 9/12/2014 N 6-16 ft SB-304-S_09122014	SB304 9/12/2014 N 16-26 ft SB-304-D_09122014
chemical_name	Media Protection Standards	GB Criteria	report_result_u n t									
O-XYLENE			ug/l	< 100 U	< 500 U	< 500 U	169	642	12.7	< 250 U	258	575
STYRENE		2200	ug/l	< 100 U	< 500 U	< 500 U	< 50.0 U	< 250 U	< 10.0 U	< 250 U	< 250 U	< 250 U
TERT-BUTYL ALCOHOL			ug/l	< 1000 U	< 5000 U	< 5000 U	< 500 U	< 2500 U	< 100 U	< 2500 U	< 2500 U	< 2500 U
tert-Butylbenzene			ug/l	< 100 U	< 500 U	< 500 U	< 50.0 U	< 250 U	< 10.0 U	< 250 U	< 250 U	< 250 U
tertiaryAmylmethylether			ug/l	< 100 U	< 500 U	< 500 U	< 50.0 U	< 250 U	< 10.0 U	< 250 U	< 250 U	< 250 U
TETRACHLOROETHENE (PCE)		150	ug/l	< 100 U	< 500 U	< 500 U	< 50.0 U	< 250 U	< 10.0 U	< 250 U	< 250 U	< 250 U
TETRAHYDROFURAN			ug/l	< 200 U	< 1000 U	< 1000 U	< 100 U	< 500 U	< 20.0 U	< 500 U	< 500 U	< 500 U
TOLUENE	1700	1700	ug/l	4750	4930	10700	13000 E	30300 E	426	10800	13400	59500 E
TRANS-1,2-DICHLOROETHENE		2800	ug/l	< 100 U	< 500 U	< 500 U	< 50.0 U	< 250 U	< 10.0 U	< 250 U	< 250 U	< 250 U
TRANS-1,3-DICHLOROPROPENE			ug/l	< 50.0 U	< 250 U	< 250 U	< 25.0 U	< 125 U	< 5.0 U	< 125 U	< 125 U	< 125 U
TRANS-1,4-DICHLOROBUTENE			ug/l	< 500 U	< 2500 U	< 2500 U	< 250 U	< 1250 U	< 50.0 U	< 1250 U	< 1250 U	< 1250 U
TRICHLOROETHYLENE		540	ug/l	< 100 U	< 500 U	< 500 U	< 50.0 U	< 250 U	< 10.0 U	< 250 U	< 250 U	< 250 U
TRICHLOROFLUOROMETHANE			ug/l	< 100 U	< 500 U	< 500 U	< 50.0 U	< 250 U	< 10.0 U	< 250 U	< 250 U	< 250 U
VINYL CHLORIDE		2	ug/l	< 100 U	< 500 U	< 500 U	< 50.0 U	< 250 U	< 10.0 U	< 250 U	< 250 U	< 250 U
Xylene (Total)	78		ug/l	273	< 1000 U	< 1000 U	821	3510	44.4	505	816	2420

Notes:
U indicates not detected above report detection limits
E indicates the concentration for this analyte is an estimated value resulting in a biased final concentration.
Bold font with purple background indicates exceedance of Media Protection Standard
Bold font with blue background indicates exceedance of RIDEM GB Groundwater Criteria

Table F-2
Corrective Measures Study - Pre Design Investigation Soil Results - September 2014
BASF - 180 Mill Street
Cranston, RI

Location ID Sample Date Sample Type Depth Interval			SB301 9/11/2014 N 10 - 12.5 ft	SB301 9/11/2014 N 15 - 17.5 ft	SB302 9/11/2014 FD 15 - 17.5 ft	SB302 9/11/2014 N 15 - 17.5 ft	SB302 9/11/2014 N 20 - 22.5 ft	SB303 9/11/2014 N 17.5 - 20 ft	SB303 9/11/2014 N 20 - 23.5 ft	SB304 9/11/2014 N 15 - 17.5 ft	SB304 9/11/2014 N 22.5 - 25 ft
Chemical Name	Unit	Industrial/Commercial DEC									
1,1,1,2-TETRACHLOROETHANE	ug/kg	220,000	< 304 U	< 347 U	< 2400 U	< 2660 U	< 2650 U	< 301 U	< 287 U	< 4720 U	< 284 U
1,1,1-TRICHLOROETHANE (TCA)	ug/kg	10,000,000	< 304 U	< 347 U	< 2400 U	< 2660 U	< 2650 U	< 301 U	< 287 U	< 4720 U	< 284 U
1,1,2,2-TETRACHLOROETHANE	ug/kg	29,000	< 304 U	< 347 U	< 2400 U	< 2660 U	< 2650 U	< 301 U	< 287 U	< 4720 U	< 284 U
1,1,2-TRICHLORO-1,2,2-TRIFLUOROETHANE	ug/kg	NE	< 304 U	< 347 U	< 2400 U	< 2660 U	< 2650 U	< 301 U	< 287 U	< 4720 U	< 284 U
1,1,2-TRICHLOROETHANE	ug/kg	100,000	< 304 U	< 347 U	< 2400 U	< 2660 U	< 2650 U	< 301 U	< 287 U	< 4720 U	< 284 U
1,1-DICHLOROETHANE	ug/kg	10,000,000	< 304 U	< 347 U	< 2400 U	< 2660 U	< 2650 U	< 301 U	< 287 U	< 4720 U	< 284 U
1,1-DICHLOROETHENE	ug/kg	9,500	< 304 U	< 347 U	< 2400 U	< 2660 U	< 2650 U	< 301 U	< 287 U	< 4720 U	< 284 U
1,1-DICHLOROPROPENE	ug/kg	NE	< 304 U	< 347 U	< 2400 U	< 2660 U	< 2650 U	< 301 U	< 287 U	< 4720 U	< 284 U
1,2,3-TRICHLOROBENZENE	ug/kg	10,000,000	< 304 U	< 347 U	< 2400 U	< 2660 U	< 2650 U	< 301 U	< 287 U	< 4720 U	< 284 U
1,2,3-TRICHLOROPROPANE	ug/kg	NE	< 304 U	< 347 U	< 2400 U	< 2660 U	< 2650 U	< 301 U	< 287 U	< 4720 U	< 284 U
1,2,4-TRICHLOROBENZENE	ug/kg	10,000,000	< 304 U	< 347 U	3330	3670	3550	< 301 U	785	< 4720 U	513
1,2,4-TRIMETHYLBENZENE	ug/kg	NE	< 304 U	< 347 U	< 2400 U	< 2660 U	< 2650 U	< 301 U	< 287 U	< 4720 U	< 284 U
1,2-DIBROMO-3-CHLOROPROPANE (DBCP)	ug/kg	4,100	< 608 U	< 694 U	< 4800 U	< 5320 U	< 5300 U	< 603 U	< 573 U	< 9450 U	< 567 U
1,2-DIBROMOETHANE (EDB)	ug/kg	70	< 304 U	< 347 U	< 2400 U	< 2660 U	< 2650 U	< 301 U	< 287 U	< 4720 U	< 284 U
1,2-DICHLOROBENZENE	ug/kg	10,000,000	< 304 U	< 347 U	136000	141000	147000	< 301 U	10800	178000	23100
1,2-DICHLOROETHANE	ug/kg	63,000	< 304 U	< 347 U	< 2400 U	< 2660 U	< 2650 U	< 301 U	< 287 U	< 4720 U	< 284 U
1,2-DICHLOROPROPANE	ug/kg	84,000	< 304 U	< 347 U	< 2400 U	< 2660 U	< 2650 U	< 301 U	< 287 U	< 4720 U	< 284 U
1,3,5- TRICHLOROBENZENE	ug/kg	NE	< 304 U	< 347 U	< 2400 U	< 2660 U	< 2650 U	< 301 U	< 287 U	< 4720 U	< 284 U
1,3,5-TRIMETHYLBENZENE	ug/kg	NE	< 304 U	< 347 U	< 2400 U	< 2660 U	< 2650 U	< 301 U	< 287 U	< 4720 U	< 284 U
1,3-DICHLOROBENZENE	ug/kg	10,000,000	< 304 U	< 347 U	< 2400 U	< 2660 U	< 2650 U	< 301 U	< 287 U	< 4720 U	< 284 U
1,3-DICHLOROPROPANE	ug/kg	84,000	< 304 U	< 347 U	< 2400 U	< 2660 U	< 2650 U	< 301 U	< 287 U	< 4720 U	< 284 U
1,4-DICHLOROBENZENE	ug/kg	240,000	< 304 U	< 347 U	< 2400 U	< 2660 U	< 2650 U	< 301 U	< 287 U	< 4720 U	< 284 U
1,4-Dioxane	ug/kg	NE	< 6080 U	< 6940 U	< 48000 U	< 53200 U	< 53000 U	< 6030 U	< 5730 U	< 94500 U	< 5670 U
2,2-DICHLOROPROPANE	ug/kg	84,000	< 304 U	< 347 U	< 2400 U	< 2660 U	< 2650 U	< 301 U	< 287 U	< 4720 U	< 284 U
2-BUTANONE (MEK)	ug/kg	10,000,000	< 3040 U	< 3470 U	< 24000 U	< 26600 U	< 26500 U	< 3010 U	< 2870 U	< 47200 U	< 2840 U
2-CHLOROTOLUENE	ug/kg	10,000,000	35700 E	4860	1020000 E	1060000 E	1270000 E	15300	420000 E	290000	169000 E
2-HEXANONE	ug/kg	NE	< 3040 U	< 3470 U	< 24000 U	< 26600 U	< 26500 U	< 3010 U	< 2870 U	< 47200 U	< 2840 U
2-PHENYLBUTANE	ug/kg	NE	< 304 U	< 347 U	< 2400 U	< 2660 U	< 2650 U	< 301 U	< 287 U	< 4720 U	< 284 U
4-CHLOROTOLUENE	ug/kg	10,000,000	1480	< 347 U	86200	88000	105000	811	32300 E	23200	16500
4-METHYL-2-PENTANONE (MIBK)	ug/kg	10,000,000	< 3040 U	< 3470 U	< 24000 U	< 26600 U	< 26500 U	< 3010 U	< 2870 U	< 47200 U	< 2840 U
ACETONE	ug/kg	10,000,000	< 3040 U	< 3470 U	< 24000 U	< 26600 U	< 26500 U	< 3010 U	< 2870 U	< 47200 U	< 2840 U
ACRYLONITRILE	ug/kg	NE	< 304 U	< 347 U	< 2400 U	< 2660 U	< 2650 U	< 301 U	< 287 U	< 4720 U	< 284 U
BENZENE	ug/kg	200,000	< 304 U	< 347 U	< 2400 U	< 2660 U	< 2650 U	< 301 U	< 287 U	< 4720 U	460
BROMOBENZENE	ug/kg	NE	< 304 U	< 347 U	15600	15800	18700	< 301 U	< 287 U	29300	13400
BROMODICHLOROMETHANE	ug/kg	92,000	< 304 U	< 347 U	< 2400 U	< 2660 U	< 2650 U	< 301 U	< 287 U	< 4720 U	< 284 U
BROMOFORM	ug/kg	720,000	< 304 U	< 347 U	< 2400 U	< 2660 U	< 2650 U	< 301 U	< 287 U	< 4720 U	< 284 U
BROMOMETHANE	ug/kg	2,900,000	< 608 U	< 694 U	< 4800 U	< 5320 U	< 5300 U	< 603 U	< 573 U	< 9450 U	< 567 U
CARBON DISULFIDE	ug/kg	NE	< 608 U	< 694 U	< 4800 U	< 5320 U	< 5300 U	< 603 U	< 573 U	< 9450 U	< 567 U
CARBON TETRACHLORIDE	ug/kg	44,000	< 304 U	< 347 U	< 2400 U	< 2660 U	< 2650 U	< 301 U	< 287 U	< 4720 U	< 284 U
CHLOROBENZENE	ug/kg	10,000,000	< 304 U	< 347 U	27600	28300	27300	< 301 U	1180	67700	30600 E
CHLOROBROMOMETHANE	ug/kg	NE	< 304 U	< 347 U	< 2400 U	< 2660 U	< 2650 U	< 301 U	< 287 U	< 4720 U	< 284 U
CHLOROETHANE	ug/kg	NE	< 608 U	< 694 U	< 4800 U	< 5320 U	< 5300 U	< 603 U	< 573 U	< 9450 U	< 567 U
CHLOROFORM	ug/kg	940,000	< 304 U	< 347 U	< 2400 U	< 2660 U	< 2650 U	< 301 U	< 287 U	< 4720 U	< 284 U
CHLOROMETHANE	ug/kg	NE	< 608 U	< 694 U	< 4800 U	< 5320 U	< 5300 U	< 603 U	< 573 U	< 9450 U	< 567 U
CIS-1,2-DICHLOROETHENE	ug/kg	10,000,000	< 304 U	< 347 U	< 2400 U	< 2660 U	< 2650 U	< 301 U	< 287 U	< 4720 U	< 284 U
CIS-1,3-DICHLOROPROPENE	ug/kg	NE	< 304 U	< 347 U	< 2400 U	< 2660 U	< 2650 U	< 301 U	< 287 U	< 4720 U	< 284 U
CYMENE	ug/kg	10,000,000	< 304 U	< 347 U	< 2400 U	< 2660 U	< 2650 U	< 301 U	< 287 U	< 4720 U	< 284 U
DIBROMOCHLOROMETHANE	ug/kg	68,000	< 304 U	< 347 U	< 2400 U	< 2660 U	< 2650 U	< 301 U	< 287 U	< 4720 U	< 284 U
DIBROMOMETHANE	ug/kg	NE	< 304 U	< 347 U	< 2400 U	< 2660 U	< 2650 U	< 301 U	< 287 U	< 4720 U	< 284 U
DICHLORODIFLUOROMETHANE	ug/kg	NE	< 608 U	< 694 U	< 4800 U	< 5320 U	< 5300 U	< 603 U	< 573 U	< 9450 U	< 567 U
Diethyl ether	ug/kg	NE	< 304 U	< 347 U	< 2400 U	< 2660 U	< 2650 U	< 301 U	< 287 U	< 4720 U	< 284 U
DIISOPROPYL ETHER	ug/kg	NE	< 304 U	< 347 U	< 2400 U	< 2660 U	< 2650 U	< 301 U	< 287 U	< 4720 U	< 284 U
ETHANOL	ug/kg	NE	< 122000 U	< 139000 U	< 959000 U	< 1060000 U	< 1060000 U	< 121000 U	< 115000 U	< 1890000 U	< 113000 U

Table F-2
Corrective Measures Study - Pre Design Investigation Soil Results - September 2014
BASF - 180 Mill Street
Cranston, RI

Location ID Sample Date Sample Type Depth Interval			SB301 9/11/2014 N 10 - 12.5 ft	SB301 9/11/2014 N 15 - 17.5 ft	SB302 9/11/2014 FD 15 - 17.5 ft	SB302 9/11/2014 N 15 - 17.5 ft	SB302 9/11/2014 N 20 - 22.5 ft	SB303 9/11/2014 N 17.5 - 20 ft	SB303 9/11/2014 N 20 - 23.5 ft	SB304 9/11/2014 N 15 - 17.5 ft	SB304 9/11/2014 N 22.5 - 25 ft
Chemical Name	Unit	Industrial/Commercial DEC									
ETHYLBENZENE	ug/kg	10,000,000	< 304 U	< 347 U	19600	20300	18300	< 301 U	4580	42200	3280
Ethyltertiarybutylether	ug/kg	NE	< 304 U	< 347 U	< 2400 U	< 2660 U	< 2650 U	< 301 U	< 287 U	< 4720 U	< 284 U
HEXACHLORO-1,3-BUTADIENE	ug/kg	73,000	< 304 U	< 347 U	< 2400 U	< 2660 U	< 2650 U	< 301 U	< 287 U	< 4720 U	< 284 U
ISOPROPYLBENZENE	ug/kg	10,000,000	< 304 U	< 347 U	< 2400 U	< 2660 U	< 2650 U	< 301 U	< 287 U	< 4720 U	< 284 U
METHYL TERT-BUTYL ETHER	ug/kg	10,000,000	< 304 U	< 347 U	< 2400 U	< 2660 U	< 2650 U	< 301 U	< 287 U	< 4720 U	< 284 U
METHYLENE CHLORIDE	ug/kg	760,000	< 608 U	< 694 U	< 4800 U	< 5320 U	< 5300 U	< 603 U	< 573 U	< 9450 U	< 567 U
m-Xylene & p-Xylene	ug/kg	NE	< 608 U	805	69400	69400	65500	< 603 U	15400	102000	11000
NAPHTHALENE	ug/kg	10,000,000	< 304 U	< 347 U	5440	7020	6180	< 301 U	1430	31100	947
N-BUTYLBENZENE	ug/kg	NE	< 304 U	< 347 U	< 2400 U	< 2660 U	< 2650 U	< 301 U	< 287 U	< 4720 U	< 284 U
N-PROPYLBENZENE	ug/kg	NE	< 304 U	< 347 U	< 2400 U	< 2660 U	< 2650 U	< 301 U	< 287 U	< 4720 U	< 284 U
O-XYLENE	ug/kg	NE	< 304 U	< 347 U	16500	17100	16200	< 301 U	3680	32200	3020
STYRENE	ug/kg	190,000	< 304 U	< 347 U	< 2400 U	< 2660 U	< 2650 U	< 301 U	< 287 U	< 4720 U	< 284 U
TERT-BUTYL ALCOHOL	ug/kg	NE	< 3040 U	< 3470 U	< 24000 U	< 26600 U	< 26500 U	< 3010 U	< 2870 U	< 47200 U	< 2840 U
tert-Butylbenzene	ug/kg	NE	< 304 U	< 347 U	< 2400 U	< 2660 U	< 2650 U	< 301 U	< 287 U	< 4720 U	< 284 U
tertiaryAmylmethylether	ug/kg	NE	< 304 U	< 347 U	< 2400 U	< 2660 U	< 2650 U	< 301 U	< 287 U	< 4720 U	< 284 U
TETRACHLOROETHENE (PCE)	ug/kg	110,000	< 304 U	< 347 U	< 2400 U	< 2660 U	< 2650 U	< 301 U	< 287 U	< 4720 U	< 284 U
TETRAHYDROFURAN	ug/kg	NE	< 608 U	< 694 U	< 4800 U	< 5320 U	< 5300 U	< 603 U	< 573 U	< 9450 U	< 567 U
TOLUENE	ug/kg	10,000,000	2620	19600	246000 E	255000	231000	6160	80500 E	95800	72000 E
TRANS-1,2-DICHLOROETHENE	ug/kg	10,000,000	< 304 U	< 347 U	< 2400 U	< 2660 U	< 2650 U	< 301 U	< 287 U	< 4720 U	< 284 U
TRANS-1,3-DICHLOROPROPENE	ug/kg	NE	< 304 U	< 347 U	< 2400 U	< 2660 U	< 2650 U	< 301 U	< 287 U	< 4720 U	< 284 U
TRANS-1,4-DICHLOROBUTENE	ug/kg	NE	< 1520 U	< 1740 U	< 12000 U	< 13300 U	< 13300 U	< 1510 U	< 1430 U	< 23600 U	< 1420 U
TRICHLOROETHYLENE	ug/kg	520,000	< 304 U	< 347 U	< 2400 U	< 2660 U	< 2650 U	< 301 U	< 287 U	< 4720 U	< 284 U
TRICHLOROFLUOROMETHANE	ug/kg	NE	< 304 U	< 347 U	< 2400 U	< 2660 U	< 2650 U	< 301 U	< 287 U	< 4720 U	< 284 U
VINYL CHLORIDE	ug/kg	3,000	< 304 U	< 347 U	< 2400 U	< 2660 U	< 2650 U	< 301 U	< 287 U	< 4720 U	< 284 U

Notes:
ug/kg micrograms/kilogram
DEC Direct Exposure Criteria
U indicates not detected above report detection limits
E indicates exceed calibration range of GC/MS instrument.
NE indicates Not Established